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TRANSACTIONS OF THE FIRST LECTURES DEDICATED TO THE DEVELOPMENT OF THE SCIENTIFIC HERITAGE OF K. E. TSIOLKOVSKIY

Edited by A. A. Blagonravov et al.

Academy of Sciences USSR, Moscow, 1967

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • APRIL 1970

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Translation of "Trudy Pervykh Chteniy, Posvyashchennykh Razrabotke Nauchnogo Naslediya i Razvitiyu Idey K. E. Tsiolkovskogo" Academy of Sciences USSR, Commission for the Development of the Scientific Legacy of K. E. Tsiolkovskiy, Moscow, 1967

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TRANSACTIONS OF THE FIRST LECTURES DEDICATED TO THE DEVELOPMENT OF THE SCIENTIFIC HERITAGE OF K. E. TSIOLKOVSKIY

ABSTRACT. This collection contains scientific reports presented at the annual Kaluga conference. These reports cover a broad spectrum of aviation and space-flight problems from the standpoint of K. E. Tsiolkovskiy's concepts. Some are devoted to the ideas, achievements, and memory of the father of modern rocketry.

FROM THE EDITORIAL BOARD

On the initiative of the scientific public in Moscow and Kaluga, we decided to conduct annual scientific Readings (Lectures), devoted to the development of the scientific legacy and concepts of K. E. Tsiolkovskiy. The organizers of these Lectures included the All-Union Committee of Cosmonautics of the USSR DOSAAF[1], the K. E. Tsiolkovskiy State Museum, the Institute of the History of Natural Science and Technology of the USSR Academy of Sciences, the Committee for the Development of the Scientific Legacy of K. E. Tsiolkovskiy under the USSR Academy of Sciences Presidium and the Institute of Medical-Biological Problems of the Ministry of Health Protection of the USSR. In 1966, at a joint session of the representatives of these organizations, the decision was made to conduct the scientific lectures annually in Kaluga, on the jubilee days of the scientist.

In the topics of the lectures, the decision was made to include research devoted to the study of Tsiolkovskiy's creativity, the development of the ideas of the great scientist, of the history of aviation and rocket science and technology, and also modern scientific research, representing the extension of Tsiolkovskiy's ideas. Since a distinguishing feature of the creativity of the pioneer of rocketry and cosmonautics was the scope and boldness of his scientific research, striving toward the remote future, the decision was made to open access to the Readings devoted to Tsiolkovskiy, to reports pertaining to futuristic, promising problems of science and the clarification of hypotheses, scientific problems just being formulated, to the realization of which mankind could proceed in the future.

The first time, the annual scientific lectures dedicated to developing the scientific legacy and the extension of Tsiolkovskiy's ideas were held in Kaluga from 17-18 September 1966, during the days of the 109th anniversary of the birthday of the scientist. In all, 17 lectures and reports were read; most of these are published in this issue.

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[1] DOSAAF=Volunteer Society for Cooperation with the Army, Navy and Air Force.

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REALIZATION OF THE IDEAS OF K. E. TSIOLKOVSKIY IN THE REPORTS OF THE GSRM[1]

M. K. Tikhonravov and Yu. V. Biryukov

As he developed the theory of interplanetary travel, Tsiolkovskiy passionately desired the most rapid realization of space flight in practice. However, realizing what tremendous difficulties stood in the way, he initially considered that the first flight into space could be achieved not earlier than the beginning of the year 2000. Thus, in the book *Vne Zemli* [Outside the Earth], he specifies the date 2017. /5[2]

But the success of building socialism in the USSR and the vast creative forces of the people brought to life by these successes made it possible for Konstantin Eduardovich to revise these periods. In his speech given in Red Square on 1 May 1933, he said: "I believe than many of us will be the witnesses of the first travel beyond the atmosphere"[3]. This daring desire of the scientist has come true.

One of the decisive factors in the revision by Tsiolkovskiy of the period of the first space flight was the successful work of the Group for Study of Reactive Motion (GSRM), organized in Moscow in 1931, which started the practical realization of his ideas. Now, when more than 35 years have passed from the time of the formation of GSRM, it is time to analyze its activity as a whole and indicate the contribution of this group to the development of Soviet rocket technology.

The history of the establishment of the GSRM has certain features in common with the history of origin of the Society for the Study of Inter-Planetary Travel (SSIT) in 1924. Both the GSRM and the SSIT developed as

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[1]GSRM = Group for the Study of Reaction Motion.

[2]Numbers in the margin indicate pagination in the foreign text.

[3]Pravda, 21 September 1935, No. 261.

social organizations, consisting of enthusiasts of rocket technology and cosmonautics, which adopted the purpose of publicizing the ideas of Tsiolkovskiy and undertaking practical work directed towards their realization. /6 Both organizations established contact with Tsiolkovskiy and he gladly extended assistance to them with his advice. Both in the GSRM and in the SSIT, people were working who believed deeply in the vast possibilities of rocketry and astronautics.

However, in spite of these common features in the history of their origins, the results of the activity of the two organizations were quite different. The SSIT succeeded in starting publicizing activity, but the Society was unable to proceed to practical work, or to organize even the most elementary experimental-production base, and, having existed for less than a year, it disbanded. However, the GSRM, having organized a production-experimental base and having gathered around itself considerable engineering forces, attained outstanding propagandistic and practical results, after about two years, together with the Leningrad Gas Dynamics Laboratory (LGDL), it was transformed into an organization of a higher level, namely the Reactive Scientific Research Institute (RSRI). This difference in results compels us to analyze the conditions under which the activity of the SSIT and the GSRM transpired. The conditions were actually different: from an agrarian country, which it still was in 1924, as a result of the struggle of the Communist Party for the industrialization of the country, the Soviet Union was converted in the early 1930's to an industrial power. As a result of the successful fulfillment of the first national-economic Five Year Plan (1929-1932), in our country we created heavy industry, machine building and aircraft industries.

In the 1930's, the possibilities for the development of aviation were already delineated more clearly and the limits of the application of the propeller-engine group began to be revealed. A number of young activists in aviation, in quest for ways of overcoming these limits, concentrated their attention on the problems of reactive propulsion, having adopted the ideas of Tsiolkovskiy not so much from a desire to fly more quickly to Mars as from a general effort to fly higher, faster and further. Of particular value to these people, in addition to the desire expressed and efforts made, was the experience already gained in working in aircraft construction; they had already made their aircraft designs, and the designs and ideas in rocketry had been conceived. They could rely on the aircraft industry, as an actual base for work on reactive aircraft. It was specifically from among these /7 people that the director of the GSRM, Sergey Pavlovich Korolev appeared, combining (along with an outstanding design talent) a profound scientific intuition and brilliant organization capability. From these same people, there also emerged the leaders of the brigades and most of the other leading workers of the GSRM.

The GSRM initially received the complete support of a powerful mass organization, *Osoaviakhim*[1], and the direct support of the People's Commissariat for military and naval affairs. It is necessary to comment that this assistance, having provided to the GSRM the large share of its material

[1] *Osoaviakhim*= Society for Assistance to the Defense Aviation and Chemical Industry.

resources, was received not only owing to the efforts of the leadership of the GSRM, directed toward proving the importance of the activities in rocketry, but also owing to the fact that these efforts enjoyed the complete understanding of the Director of Armaments of the WPRA (Workers and Peasants Red Army), M. N. Tukhachevskiy, who visualized the rocket as the basis for the armament of the future.

As follows from the foregoing discussion, the creation of the GSRM as the organization which started the practical operation in the development of rocketry, resulted from the general pace of scientific-technical progress in our country and was accompanied by a number of favorable factors. Nevertheless, in reality, the GSRM workers were compelled to apply truly heroic efforts to fulfill their historical mission as the founders of the Soviet liquid rockets.

The Moscow Group for the Study of Reactive Motion was organized in August, 1931. This decision was promoted by the activity of S.P. Korolev, directed toward the development of a rocket plane powered by a rocket engine based on liquid fuel (LFRE), the OR-2, designed by F. A. Tsander. The GSRM performed extensive publicizing activity. On 13 November 1931, the GSRM organized a branch in Leningrad and soon the *Osoaviakhim* [Society for Assistance to the Defense Aviation and Chemical Industry] began to create GSRM branches across the country. After this, the Moscow GSRM came to be called the central unit (CGSRM), and it was assigned the management of all the remaining groups. At the beginning of 1932, the CGSRM organized the world's first courses on rocketry, which played their part in training the staffs of rocketmen in our country.

On 3 March 1932, at a meeting of the Revolutionary Military Council, under the chairmanship of Tukhachevskiy, a lecture was given by the leaders of the CGSRM concerning the problems of jet propulsion and a resolution was adopted concerning the need for creating an active Scientific-Research Institute. Prior to its realization, the Administration of Military Inventions was authorized to make the necessary resources available for the operation of the GSRM. As a result, in April 1932 a resolution was adopted concerning the /8 creation of an Experimental Rocket Plant of the CGSRM which became established in the minds of the people as the historical GSRM. S. P. Korolev was appointed the director of this plant and also the director of the CGSRM and of its technical council.

While all who desired took part in the work of the CGSRM and the local GSRM groups, only specialists having the necessary training participated in the production GSRM. Initially, they all worked on a social basis, and only later,as the people became involved in the work, were they accepted on the staff of the GSRM. The financing on the part of Administration of Military Inventions of the WPRA (Workers and Peasants' Red Army) permitted the group of the GSRM not to be restricted only to activities in the area of rockets, but to proceed to work on a number of other topics, partially advanced by Korolev and Tsander, and M. K. Tikhonravov and Yu. A. Pobedonostsev, who had arrived to work in the GSRM.

After overcoming numerous organizational difficulties associated with the search for facilities and equipment, with arranging for material supplies, the GSRM plant became a scientific-research laboratory, consisting of four planning-design teams, and production workshops serving them. The first team was supervised by F. A. Tsander, the second by M. K. Tikhonravov, the third by Yu. A. Pobedonostsev and the fourth by S. E. Korolev. Numbers were assigned to the teams in the order of their organization. The topics and the objects having been developed in the GSRM had a successive numbering, with the prefixing of a zero for one-digit numbers. In all in the GSRM, ten planning-research objects or themes were developed.

The first team developed the following topics:

01 - experimental researches using the OR - 1 test rocket engine,

02 - the OR - 2 rocket engine, and

10 - the liquid fuel rocket.

F. A. Tsander built his first OR-1 engine in 1930. This engine operated on gasoline and air and had a thrust of several hundreds of grams, and at maximal load, up to 5 kg. Upon joining the GSRM, Tsander used the OR-1 engine for testing metal fuels; he was a devoted advocate of the idea of using this type of fuel. He burned magnesium and certain other metals. These activities were not carried through to the practical utilization of metal fuel owing to the difficulties in the organization of its delivery to the combustion chamber.

The development of the design for the OR-2 rocket engine was started by Tsander immediately after the organization of the GSRM. Evidently, the idea of the development of this engine originated as early as mid-1930 or the beginning of 1931. /9

According to the design, the OR-2 was a liquid-fuel aircraft engine based on liquid oxygen and gasoline with a thrust of 50 kg. Control of the thrust was provided by reducing fuel consumption.

The tests on the OR-2 were started on 18 March 1933 and were supervised by A. I. Polyarnyy. Since the engine functioned erratically and quickly burned out, it was converted to using a 96% alcohol solution. The oxidizer remained the same. In addition, a number of modifications were introduced, dictated by the results of the experimental work with the engine; the engine itself was considerably simplified. For example, the liquid oxygen evaporators, the nitrogen compensator, and the devices controlling the fuel consumption were eliminated. The all-metal cooled combustion chamber was replaced by a ceramic one. All these changes were introduced by the students of Tsander after his death on 28 March 1933.

During the tests, the design thrust was obtained. The engine was intended for installation on a rocket plane; the development of an airframe in Autumn 1931 was entrusted to the aircraft designer B. I. Cheranovskiy. It was built in three months and was given the code symbol RP-1(airframe BICH-II).

However, the development of the 02 rocket engine was not finished in the GSRM. This work was transferred to the Reactive Scientific-Research Institute (RSRI); it was successfully completed there. The 02 engine was used at RSRI in wingless and winged rockets.

Rocket 10, the number of which is sometimes written as X, was conceived by F. A. Tsander as utilizing a metal fuel; a part of the rocket body itself was to serve as this fuel. Thus, in this rocket, the foundation for the practical realization of one of the basic ideas of F. A. Tsander was to be laid. However, after his death, the rocket was subjected to remodelling and was converted to a liquid-fuel rocket (liquid oxygen, alcohol) of a conventional system with the fuel fed into the engine by compressed air. The liquid-fuel rocket engine for this rocket was proposed by Tsander.

Rocket 10 was started on the proving ground in Nakhabino on 25 November 1933. After a normal exit from the launching stand, during the third or fourth second of operation the engine turned in its supports, since the /10
brackets retaining it proved to be too weak; at this time, the alcohol tank broke away. At a height of around 80 meters, the rocket turned, and by inertia moved over a forest and broke up.

Those who worked in the first team included L. S. Dushkin, A. I. Polyarnyy, L. K. Korneyev, L. N. Kolbasina, Ye. K. Moshkin, A. I. Podlipayev, and others.

In the second team supervised by M. K. Tikhonravov, the following topics were developed:

- 03 - RDA-1 engine with pump delivery of fuel components for the RP-2 rocket aircraft,
- 05 - a rocket with a nitric-acid engine ORM-50 of the GDL design,
- 07 - a rocket with engine using lox and kerosene, and
- 09 - a rocket utilizing a fuel of a mixed composition, the main part of which was formed by lox.

The main emphasis in the work on the 03 engine, intended for 100 kg thrust, was in the development of the lox feed pump. Gasoline was suggested as a fuel.

The operating principle of the pump consisted in the idea that a part of the liquid (of the lox) which was being pumped should be evaporated, and the pressure of the vapors would feed the remaining major part to the engine.

In 1932, drawings of such a pump were prepared. However, its manufacture was delayed. This work was later turned over to the RSRI[1], where a device for testing the pump was built. However, there also, the manufacture of the pump was not completed. By this time, it became clear that the development of the combustion chamber for a rocket engine is a very difficult problem. All of the efforts were concentrated on this task; the work on the pump was temporarily abandoned.

The 07 rocket was the first rocket on which the second team of the GSRM began to work. Its engine was to operate on lox and kerosene. The fuel tanks were installed in the rocket stabilizer, while the liquid-fuel engine was placed between them. The fuel was fed by the pressure from the oxygen vapors.

The development of the 07 rocket engine was not finished in the GSRM. The 07 rocket project was transferred to the RSRI, where subsequently, the rocket flew.

The next rocket assigned to the second team was the 09 rocket. It was planned for fuel consisting of lox and thickened gasoline. The thickened gasoline was prepared in the city of Baku and was a solution of gasoline and /11 resin. Under normal conditions, the thickened gasoline had the consistency of cup grease or of technical vaseline, and burned in parallel layers. Its heat-production was around 9,000 kcal/kg. The 09 rocket engine was a chamber made of sheet brass with a bronze head and a bronze recess for the nozzle. The nozzle was made of steel. Into the head was turned a starting valve connected directly with the oxygen tank,, made of a Dural tube. The lox was fed by the pressure of its own vapors. A manometer was installed in the rocket for observing the increase in the pressure. The thickened gasoline was placed directly in the combustion chamber between the special cylindrical metal grid and the chamber walls. The ignition was accomplished with an aircraft sparkplug, turned into a sleeve located in the combustion chamber. The frame, within which the engine and tank were installed, was made of Duraluminum 0.5 mm in thickness. The stabilizers were made of Elektron (magnesium-base alloy). The fully-equipped rocket weighed 19 kg. Its photographs appeared many times in the technical and popular literature.

The development of the system of the 09 rocket engine continued in the Spring and Summer of 1933. The thrust was measured on a balancing device and averaged 37 kg.

On 17 August 1933, the first launching of the rocket took place and was successful. The rocket reached a height of around 400 m. The launching was performed vertically. This was the first Soviet liquid-fuel rocket to be launched.

The second launching of the 09 rocket took place in late Autumn of 1933; after it had risen to a height of more than 100 m, for an unexplained reason,

[1] RSRI = Reactive Scientific Research Institute.

the engine exploded in air. Later, in the RSRI, a series of six 09 rockets were prepared (there they were given the number 13); successful launchings were conducted at an angle for studying the possibility of the usage of rockets based on liquid fuel as artillery.

The planning of the 05 rocket was begun after the 07 and 09 rockets. This rocket was designed for an ORM-50 engine designed at GDL[1], operating on nitric acid and kerosene. The construction of this rocket was completed in 1933 in the period of the organization of the RSRI, where further development took place. In the RSRI, on the basis of the 05 rocket, with the material support of *Aviavnito*[2], the stratospheric rocket "*Aviavnito*" was developed. The rocket utilized the "12 k" ceramic engine with 300 kg thrust, with an operating time of 60 seconds, operating on lox and 96% alcohol. However, in the 05 rocket, the stabilizers, which were taken from the unfinished RDD-II high altitude rocket were replaced. The blades of these stabilizers were /12
shaped and hollow. The rocket had a launch weight of 100 kg, of which 32 kg was fuel. The engine yielded a specific thrust of 205-207 kg sec/kg. The weight of the entire engine assembly was 15 kg. According to the design, the rocket was to rise to a height of 10,800 meters. A parachute was placed in the nose of the rocket. A device for measuring the height of ascent was installed in the rocket. This device, of a barograph type, was developed by S. A. Pivovarov.

The first launching of the "*Aviavnito*" rocket was accomplished on 6 April 1936. This launching was reported in the newspaper "Pravda" under the headline "A Rocket Moves Into the Air". In the same place, a photograph of the rocket, prior to launching, in the launching platform, was included. Here was how the correspondent of this newspaper described the flight of the rocket: "The technician closed the knife switch of the electrical fuse. Grey smoke from the burning fuel appeared. Sparks became visible. A blinding yellow tongue appeared suddenly at the base of the rocket. The rocket slowly moved upward, guided by the platform rods, slid out of its steel retainers and struggled upward. The flight was an unusually impressive and pretty sight. Flame flew out of the engine nozzle; the efflux of the gases was accompanied by a deep, low sound. After rising to some height, the white dome of the parachute opened above the rocket, and it descended smoothly onto the snowy field". [1].

For the subsequent launchings, a wooden mast 48 m high with a directing gib which enclosed the retaining lugs of the rocket was built. The rail from a narrow-gauge railway was used for a gib. This mast was utilized as a launching stand.

On 15 August 1937, a successful launching was performed to a height of around 3,000 m. During the descent, the parachute opened but its attachments broke off. The rocket was destroyed.

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[1] GDL = Expansion unknown.

[2] *Aviavnito* = All-Union Aviation Scientific Research Society.

The second team of the GSRM included F. L. Yakaytis, V. S. Zuev, V. N. Galkovskiy, Z. I. Kruglova, O, K. Parovina, N. I. Shul'gina, V.A. Andreyev, Ye. I. Snegireva, N. I. Yefremov, and others.

In the third team, supervised by Yu. A. Pobedonostsev, the following topics were developed:

04 - the IU-I installation for obtaining air streams at supersonic velocities,

08 - a missile with a uniflow airfeed-jet engine.

The supersonic IU-I device consisted of a compressor, batteries of tanks, a receiver and a chamber with a nozzle for creation of a supersonic airflow. The facility was completely finished by March, 1933. Hydrogen (from a special tank) was burned as required to change the temperature of the airflow, in the chamber at the head of the nozzle. The facility was the first installation of such a type in the USSR and produced the air stream velocities of up to M = 2.7 at normal temperature. Later, in the RSRI, the IU-I device was improved by Yu. A. Pobedonostsev. The critical M value was raised to 3.2 (a flow velocity of more than 1,000 m/sec). /13

The IU-I installation served as a prototype of the supersonic wind tunnel which was developed in the RSRI and then in a number of other establishments. The results of the work of the GSRM along these lines were reported by Pobedonostsev at the All-Union Conference on the Study of the Stratosphere convened by the USSR Academy of Sciences, and published in the Transactions of this conference.

In the development of object 08, the task posed was increasing the firing range of conventional artillery by using an air-jet rocket engine placed inside an artillery shell. The object of the testing chosen was the long-range shell of a 76 mm gun. As fuel, yellow phosphorus was chosen, and was used to fill special cells made of aluminum, built in along the periphery of the air-feed jet engine. Thus, the uniflow air-feed rocket engine of object 08 operated on solid fuel. The designers developed the design of the shell, the technique of its production, the technique of loading the phosphorus, the rules for storage and operation, as well as the firing procedure.

Only preliminary firings were conducted with the 08 missile in the GSRM. A range of 12% farther than the range under identical conditions with the corresponding normal missile, and 60% more than the range of an 08 missile with non-functioning air-feed jet engine[1] was obtained after the transfer of this work to the RSRI.

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[1] Refer to M. S. Kisenko for a detailed description of the tests with this craft. "First Experiment in Flight of an Air-Feed Rocket Engine". *Raketnaya Tekhnika* [Rocket Technology], No. 9, 1940.

Those who worked in the third team included G. I. Ivanov, V.A. Timofeyev, I. A. Merkulov, M. S. Kisenko, A. B. Ryazankin and others (M. S. Kisenko and A. B. Ryazankin died at the front in World War II from 1941 - 1945). /14

In the fourth team supervised by S. P. Korolev, the development continued on the RP-1 rocket aircraft with the OR-2 engine; work was conducted on the RP-2 rocket aircraft with the 03 engine and the future rocket aircraft RP-3. Topic 06, namely pilotless winged rocket apparatus, was developed. The engine and the tanks of the RP-1 rocket aircraft were placed in its wing. The attachment of the fuel tanks permitted them to be ejected during flight. This was provided owing to the danger of possible fire; this also explains the pear-shape of the engine tanks and the presence in its design of a special sleeve around the main valves of the fuel and oxidizer (nozzles), filled during engine operation with carbon dioxide gas.

Initially, the RP-1 rocket aircraft flew as a glider. The pilot was S. P. Korolev. Later, designer V. I. Cheranovskiy installed the ABC "Scorpion" aircraft engine in it, and flights were accomplished in Summer, 1931.

Ye. S. Shchetinkov, G. N. Fedotov, A. V. Chesalov, V. V. Gorbunov, V.I. Ivanova and others worked in the fourth team.

Along with the leaders and the workers of the teams, a major contribution to the work of the GSRM was made by its technicians and workers: L. A. Ikonnikov, B. V. Florov, V. P. Avdonin, I. V. Vlasov, Ye. M. Matysik, I. I. Moiseyev, B. Shedko, A. S. Rayetskiy, M. G. Vorob'yev, P. S. Aleksandrov and others. The above analysis of the work of the GSRM teams provides the basis for forming the following conclusions.

As a result of the activity of the GSRM, the foundation was laid for the practical realization of the following problems in rocketry:

1. The usage of lox as a rocket oxidizer in combination with various fuels.

2. The all-metal liquid-propellant rocket engine, with flow cooling by one of the fuel components.

3. A liquid-propellant rocket engine (LPRE) with a ceramic heat-insulating internal surface of the chamber.

4. A rocket engine with fuel components consisting of different types of materials.

5. The pump delivery of liquid oxygen (lox).

6. A rocket aircraft equipped with an LPRE, and a winged rocket.

7. A ballistic rocket.

8. A missile with a direct-flow air-feed jet engine based on an action reaction system. The studies along these lines provided the first experimental proof of the operating ability of the direct-flow air-feed jet engine in flight. /15

9. A supersonic wind tunnel.

Experiments were conducted to some degree or other in all of these areas. In most instances, results were obtained which later were used as the basis for the actual purposeful developments.

On the basis of all these activities, a group was formed which (along with the GDL group) served as a basis for forming the RSRI.

In this manner, most of the trends in the development of modern rocket technology have their roots in the activities of the GSRM. The basic and primary problem of the GSRM was to prove, by testing, the fitness of the reactive principle of propulsion with the general state-of-the-art which existed in those years. This was indeed accomplished. Moreover, it was done convincingly, at a high scientific-engineering level and in a surprisingly brief period. As a result of the activities of the GSRM and the GDL, in the USSR, the foundation of modern rocket construction was laid, as a young and promising branch of science and technology, having constituted the basis of astronautics; the ideas of K. E. Tsiolkovskiy had begun to bear fruit.

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2. Anonymous, *Pravda*, No. 99 (67705), 9 April 1936.

OPTIMAL FLIGHT REGIMES OF AIRCRAFT EQUIPPED WITH ROCKET ENGINES

A. A. Kosmodem'yanskiy

1. The well-known formula of Tsiolkovskiy for the velocity of a rocket in free space was published in 1903 in the journal *Nauchnoye Obozreniye* (Scientific Review), No. 5. In our notations, this formula has the appearance: /16

$$v_{max} = v_o + V_r \ln M_o / M_E \tag{1}$$

where v_o = the initial velocity, V_r = relative velocity of rejection of particles, M_o = the initial rocket mass, M_E = the mass of the rockets without fuel and v_{max} = the maximal rocket velocity at the end of active sector.

If we introduce into the discussion the relative final mass of the rocket $f_E = M_E/M_o$, Eq. (1) can be written further in the form:

$$v_{max} = v_o + V_r \ln \frac{1}{f_E} . \tag{2}$$

For a comparison with the following results, it is advantageous to introduce into the discussion a certain typical time of rocket flight;

$$t_{max} = \frac{v_{max}}{g_r} = \frac{v_o}{g} + \frac{V_r}{g} \ln \frac{1}{f_E} . \tag{3}$$

It is known that

$$V_r/g = J_s$$

is the specific impulse of a rocket engine, while we symbolize the value v_o/V_r as ϕ_o, then, it is convenient to write (3) in the following form

$$t_{max} = J_s \left(\varphi_0 + \ln \frac{1}{f_F} \right). \tag{4}$$

The Tsiolkovskiy formula (2) or its modification (4) reveals the maximal possibilities of the reactive method of imparting motion in free space (or in a field of gravitational force with instantaneous burning of the available fuel supply). /18

2. The purpose of the present paper is to study the maximal possibilities of the reactive method of imparting motion for the horizontal flight of an aircraft, taking into account the aerodynamic forces and the force of gravity.

The equations for the motion of an aircraft will be more complex than the equation of motion of a rocket in free space; the direct analytical study of these equations is evidently impossible, since the equations are not linear and are not integrated by known functions.

In a number of our reports starting from 1946, it was demonstrated that with the aid of the methods of the calculus of variations, we can separate from the infinite diversity of conditions for the motion of aircraft equipped with rocket engines the *optimal conditions* for which the nonlinear differential equations of dynamics become most pliable and in a number of cases permit (integration in quadratures) leading, in final analysis, to fairly simple calculation formulas.

The aerodynamic equations for the lift and drag will be written in the form:

$$Y = \frac{1}{2} C_y \rho S v^2 \tag{5}$$

$$X = \frac{1}{2} C_x \rho S v^2 \tag{6}$$

where C_x = the drag factor, C_y = the lift coefficient, ρ = the air density, S = the area of aircraft wing, v = the flight speed. For a broad range of speeds from the slow subsonic to near-escape velocities, the aerodynamic factors C_x, C_y will depend on the Mach numbers, the Reynolds numbers, and also on the angle of attack. Subsequently, we will assume that the equation of the aircraft *polar* can be written in the form:

$$C_x = C_{xo} + B\,C_y^{\,n} \tag{7}$$

where C_{xo}, B, n are constant values. (C_{xo} = the drag coefficient at zero lift). In modern aerodynamics, it is shown that for the subsonic velocities /18 n = 2, C_{xo} and B depend on the aerodynamic arrangement of the aircraft, but for the subsonic range of speeds, they are constant values. For very high speeds (more than 2,000 m/sec), n = 3/2, while C_{xo} and B are also constants, determined by experiment for the chosen layout of the aircraft. In the range of flight speeds from 250 m/sec to 2,000 m/sec. Eq. (7) can be regarded as an interpolation formula, wherein the selected flight speed ranges, C_{xo}, B, n are so selected that the theoretical polar (7) is as close as possible to the actual polar obtained from natural or model experiments.

3. Assume that an aircraft equipped with a rocket engine will move horizontally and that the lift and drag are determined by Eqs. (5) and (6). Let us conduct further calculations for the case of a parabolic polar, when in Eq. (7), n = 2[1]. Assuming that during the burning of the fuel, the center of the aircraft's mass does not shift relative to the frame of the fuselage, we will write in the following form the differential equations of motion in projections onto a tangent and perpendicular to the trajectory (onto horizontal and vertical lines):

$$M\frac{dv}{dt} = -\frac{dM}{dt}V_r - \frac{1}{2}C_x \rho S v^2 \tag{8}$$

$$0 = -Mg + \frac{1}{2}C_y \rho S v^2 . \tag{9}$$

In equations (8) and (9), M = the mass of the aircraft at a given moment, v = velocity of the aircraft's center of mass, V_r = the effective relative velocity of the combustion products at the nozzle exit of the jet engine. g = = the acceleration of gravity = const. Assuming $C_x = C_{xo} + B C_y^2$, $M = M_0 f$ where M_0 = the mass of the aircraft at the moment it enters a given horizontal line, and knowing that for these flight angles of attack $C_y = K\alpha$, where k = /19 = const, α = the angle of attack, we can write Eqs. (8) and (9) as follows:

[1] It was proved by us that the integral characteristics of motion, i.e., the path traversed and the flight duration, do not depend on n. Therefore, the solution for n = 2 is universal, if C_{xo} and B are constant.

$$f\frac{dv}{dt} = -\frac{df}{dv}V_r - \left(\frac{C_{x0}\rho S}{2M_0}\right)v^2 - \frac{bC_y^2}{2M_0}\rho S v^2 \qquad (10)$$

$$k\alpha = \frac{2M_0 fg}{\rho S v^2}. \qquad (11)$$

Since

$$\frac{df}{dt} = \frac{df}{dv}\cdot\frac{dv}{dt} = f'\frac{dv}{dt}$$

and assuming

$$\frac{C_{x0}\rho S}{2M_0} = A \;;\quad \frac{2M_0 g^2 b}{k^2\rho S} = B$$

from (10)and (11), we can obtain the following nonlinear differential equation for the function v (the equation of horizontal flight of an aircraft for a parabolic polar):

$$\frac{dv}{dt} = -\frac{Av^2 + Bf^2/v^2}{(f + f'V_r)}\;. \qquad (12)$$

In Eq. (12) $f = f(v)$ is a function characterizing the variation of the relative mass of the aircraft. To each law of the variation in mass, i.e. to each function $f(v)$, there will correspond a quite specific law of the aircraft's motion. Let us remark that the law of the variation in mass is arbitrarily assigned, Eq. (12) is not integrated, and quantitative results can be obtained only by numerical integration. However, if we subject the choice of the function $f(v)$ to a certain additional condition of optimality of the integral characteristics of motion, the methods of the calculus of variations permit us to obtain a simple analytical solution.

From (12), we easily find that:

$$dt = -\frac{(f + f'V_r)v^2 dv}{Av^4 + Bf^2} \qquad (13)$$

$$dL_a = v\,dt = -\frac{(f+f'V_r)v^3\,dv}{Av^4+Bf^2}. \qquad (14)$$

Assume that at the initial moment (at the moment of the entry of the aircraft onto the horizontal rectangular trajectory) $M = M_o$, $f = 1$, $v = v_o$, while at the end of the active flight sector (i.e. after the consumption of the fuel supply), $M = M_E$, $f = f_E < 1$, $v = v_E$. The flight time in the active sector and the course covered during this time, L_a, can be written in the form of the following functionals: /20

$$T = \int_{v_E}^{v_o} \frac{(f+f'V_r)v^2\,dv}{Av^4+Bf^2} \qquad (15)$$

$$L_a = \int_{v_E}^{v_o} \frac{(f+f'V_r)v^3\,dv}{Av^4+Bf^2}. \qquad (16)$$

Proceeding from (15) and (16), we can formulate different variation problems of the aircraft flight dynamics with a rocket engine. We will provide a solution of the two most important practical problems, those on the investigation of the conditions of maximum duration of horizontal flight and the maximum range of horizontal flight.

4. Let us study the problem concerning the regime providing maximum duration of horizontal flight, proceeding from (15). Let us formulate the problem mathematically in the following way: - among the class of functions $f = f(v)$, let us find that function which provides the maximum of integral (15) i.e. assures the maximum flight duration. From the structure of the integral (15) it is obvious that the problem formulated is a simple problem of the calculus of variations.

If we assume

$$F = \frac{(f+f'V_r)v^2}{Av^4+Bf^2}$$

the necessary condition of the extreme T (of the extreme of integral (8)), can be written in the form of the well-known Euler equation:

$$\frac{d}{dv} \cdot \frac{\partial F}{\partial f'} - \frac{\partial F}{\partial f} = 0. \qquad (17)$$

Knowing the analytical expression F = F (v, f, f^1) and calculating the derivatives, from (17) we can derive the following equation of the extremal

$$f = \sqrt{A/B} \; {}^1\!/v^2. \qquad (18)$$

Since where $v = v_0$, f = 1, (18) can also be represented as:

$$f = \frac{v^2}{v_0^2}. \qquad (19)$$

Knowing (18) or (19) and returning to (13) and (14), we can determine by simple quadratures all of the basic characteristics of optimal motion[1]. The calculations give us: /21

$$t = \frac{K_{max}}{g}\left[(v_0 - v) + 2V_r \ln \frac{v_0}{v}\right] \qquad (20)$$

$$L = \frac{K_{max}}{g}\left[\frac{1}{2}(v_0^2 - v^2) + 2V_r(v_0 - v)\right] \qquad (21)$$

where $K_{max} = \left(\frac{C_y}{C_x}\right)_{max}$ is the maximal quality of the aircraft. At the end of

[1]We can demonstrate that $1/2\sqrt{AB} = K_{max}/g$ where $K_{max} = \left(\frac{C_y}{C_x}\right)_{max}$. Refer to A. A. Kosmodem'yanskiy. *Dinamika Kosmicheskogo Poleta*, No. 1, p. 129, 1964.

the active flight sector, when $M = M_E$, $f = f_E$, $v = v_E$, (19) it follows that $v_E = v_o \sqrt{f_E}$. Therefore, the calculation equation for the maximal duration we must set $v = v_E$ in (20):

$$T_{max} = \frac{K_{max}}{g}\left[v_o(1-\sqrt{f_E}) + V_r \ln \frac{1}{f_E}\right]. \tag{22}$$

The path traversed in the time T_{max} will be:

$$L_{Jo} = \frac{K_{max}}{g}\left[\frac{v_o^2}{2}(1-f_E) + 2V_r v_o(1-\sqrt{f_E})\right]. \tag{23}$$

Equations (20-23) established the basic regularities of the optimal horizontal flight of an aircraft equipped with a rocket engine. Let us note a certain similarity of (22) with the Tsiolkovskiy formula written in the form (4).

If in (22), we move V_r from within the brackets and signify as previously $V_r/g = J_s, \frac{v_o}{V_r} = \varphi_o$, (22) will then acquire the form:

$$T_{max} = K_{max} J_s \left[\varphi_o(1-\sqrt{f_E}) + \ln \frac{1}{f_E}\right]. \tag{24}$$

The first term within the brackets (in 24) takes into account the non-stationary state of the optimal motion; the second term has the same meaning as in the Tsiolkovskiy formula (4).

A comparison of Eqs. (4) and (24) indicates that the aircraft is the best receiver of a reactive pulse, since in Eq. (24), in front of $(\ln 1/f_E)$ we have the factor $K_\sigma = K_{max} I_s$ which for the actual designs is always larger than I_s, since usually maximal quality of an aircraft /22

$$K_{max} > 5.$$

The coefficient K_σ, taking into account both the improvement of aerodynamic layout of the aircraft and the improvement of the rocket engine, should, we suggest, be called the improvement factor of the aircraft. We should remark that an aircraft equipped with air-feed jet engines, I_s is almost an order of magnitude higher than in aircraft equipped with rocket engines. Taking into account that during flights near the Earth's surface (flight altitude less than wing chord), the numerical value of quality can be increased by 2-3 times, evidently the development of aircraft with high K_σ values has serious possibilities.

Let us cite a numerical example. Assume that $K_{max} = 12$, $v_o = 300$ m/sec (subsonic aircraft) $f_E = 0.49$ (i.e. the fuel supply equals 51% of the initial aircraft weight), $V_r = 3{,}000$ m/sec, $g \cong 10$ m/sec^2, from (22), it follows that

$$T_{max} - 2{,}700 \text{ sec (i.e., 45 minutes)}$$
$$L_a = 675.5 \text{ km.}$$

5. Let us comment on certain typical features of optimal motion realizing the maximal duration of horizontal flight of an aircraft.

First of all, let us demonstrate that the optimal motion of an aircraft at $T = T_{max}$ is a gradual motion. In reality, let us differentiate (20) in respect to time, then we will obtain:

$$q = K_{max}\left[\left(-\frac{dv}{dt}\right) - \frac{2V_r}{v}\frac{dv}{dt}\right]$$

from which

$$\frac{dv}{dt} = \frac{-qv}{K_{max}(v + 2V_r)}. \tag{25}$$

The decrease in the flight speed at optimal motion also follows from the equations of the extremal in the form (19).

Let us determine the ratio of the initial thrust Φ_o of a rocket engine to the initial weight of an aircraft.

We will have: $$\frac{\Phi_0}{M_0 g} = \frac{-M_0\left(\frac{df}{dv}\right)_0\left(\frac{dv}{dt}\right)_0 V_r}{M_0 g}.$$ /23

But, from (25), it follows that

$$\left(-\frac{dv}{dt}\right)_0 = \frac{g v_0}{K_{max}(v_0+2V_r)},$$

while from (19), we easily determine:

$$\left(\frac{df}{dv}\right)_0 = \left(\frac{2v}{v_0^2}\right)_0 = \frac{2}{v_0}$$

and consequently,

$$\frac{\Phi_0}{M_0 g} = \frac{1}{K_{max}\left(1+\frac{v_0}{2V_r}\right)}. \qquad (26)$$

We find from (26) that the initial required thrust for optimal horizontal flight to achieve $T = T_{max}$ will be:

$$\Phi_0 = \frac{M_0 g}{K_{max}} \cdot \frac{1}{(1+v_0/2V_r)}. \qquad (27)$$

It is well-known that under stationary flight conditions:

$$\Phi_0^{(stat)} = M_0 g/K_{max}$$

where $\Phi_0^{(stat)}$ = the stationary value of required thrust, if we disregard the variation in aircraft mass and consider the velocity to be constant, equalling v_o.

In this manner, the presence of negative acceleration at optimal motion decreases the value of required thrust for horizontal flight.

We can write the calculation formula for the required thrust at any velocity in the form:

$$\Phi_{req} = \frac{\Phi_{req}^{(stat)}}{(1 + v/2V_r)}. \qquad (28)$$

Knowing that an optimal motion

$$f = \frac{v^2}{v_0^2}; \quad gt = K_{max}\left[(v_0 - v) + 2V_r \ln \frac{v_0}{v}\right],$$

we can easily find graphically $f = f(t)$, i.e. the law of the variation of /24

relative mass of the aircraft as a function of time. In reality, calculating the values of the functions f and t for the same values of v, we can find the table of the function f (t).

Proceeding from Eqs. (22) and (23), we can write T_{max} and L_a in the form of functions of several (basic) variables

$$T_{max} = T_{max}(g, K_{max}, v_0, V_r, f_E)$$

$$L_a = L_a(g, K_{max}, v_0, V_r, f_E).$$

If the basic variables receive the small increments $\delta g, \delta K_{max}, \delta v_0, \delta V_r, \delta f_E$ then the increments $\delta T_{max}, \delta L_a$ can, limiting ourselves to the linear terms, be written as:

$$\delta T_{max} = \frac{\partial T_{max}}{\partial g}\cdot\delta g + \frac{\partial T_{max}}{\partial K_{max}}\cdot\delta K_{max} + \cdots\cdots + \frac{\partial T_{max}}{\partial f_E}\delta f_E,$$

$$\delta L_a = \frac{\partial L_a}{\partial g}\cdot\delta g + \cdots\quad\cdots + \frac{\partial L_a}{\partial f_E}\delta f_E .$$

The appropriate values of the partial derivatives permit us to evaluate the degree of the influence of small variations in the basic parameters for T_{max} and L_a. Here, we will present a table of the partial derivatives, determining δT_{max}.

$$\frac{\partial T_{max}}{\partial g} = -\frac{K_{max}\left[v_0(1-\sqrt{f_E}) + 2V_r \ln 1/\sqrt{f_E}\right]}{g^2}; \tag{29}$$

$$\frac{\partial T_{max}}{\partial K_{max}} = \frac{v_0(1-\sqrt{f_E}) + 2V_r \ln 1/\sqrt{f_E}}{g} . \tag{30}$$

$$\frac{\partial T_{max}}{\partial v_0} = \frac{K_{max}(1-\sqrt{f_E})}{g} . \tag{31}$$

$$\frac{\partial T_{max}}{\partial V_r} = \frac{2K_{max}\ln 1/\sqrt{f_E}}{g} \tag{32}$$ /25

$$\frac{\partial T_{max}}{\partial f_E} = -\frac{K_{max}(v_0/2\sqrt{f_E} - V_r/f_E)}{g} . \tag{33}$$

For an illustration of the sequence of calculations, let us use Eq. (33), having estimated the variation in T_{max} and L_a provided that $\delta_{f_E} = -0.01$ (i.e. the fuel supply has increased by 1%), while g, V_r, v_o, K_{max} have remained unchanged. The initial data are the same as on page 12. Simple calculations yield

$$\delta T_{max} = 76 \text{ sec.}$$

$$\delta L_a = 15.96 \text{ km.}$$

Let us further calculate δT_{max} at $f_E = 1$, i.e. for the beginning of the flight. From Eq. (33), we will have:

$$\delta T_{max} = 37.8 \text{ sec.}$$

A comparison of the results of the calculations indicates the quite significant effect (upon the flight duration) of the *last* percentages of the available fuel supply. We should also direct attention to the considerable variation in all the partial derivatives with an increase in the relative fuel supply.

Let us remark that the value of the initial velocity v_o can be determined either by utilizing Eq. (18), or from the condition that at any moment of horizontal flight, the lift should equal the weight of the aircraft. Let us write that at $v = v_o$, $f_E = 1$ and $C_y = (C_y)_{\text{at } K_{max}} = C_{y_{max}}$, the lift equals

$$\frac{1}{2} C_{y\,max} \rho S v_o^2 = M_o g,$$

from which

$$v_o = \sqrt{\frac{2 M_o g}{C_{y\,max}\, \rho \cdot S}}.$$

Having signified

$$\frac{M_o g}{S} = P_o$$

we obtain

$$V_0 = \frac{1}{\sqrt{\rho}} \cdot \sqrt{\frac{P_0}{C_{y\,max}}} \quad (34)$$

From (34), it follows that we can always find a flight altitude (a value for P), at which the initial velocity will acquire a prescribed value. /26

6. Let us investigate further the optimal conditions of horizontal flight of an aircraft, realizing the maximal range of the active sector. The functional (16) can be studied quite analogously to functional (15), but the function F_1, satisfying the Euler equation, will have the following form:

$$F_1 = \frac{(f + f' V_r) v^3}{A v^4 + B f^2} . \quad (35)$$

Calculating the derivatives

$$\frac{\partial F_1}{\partial f'}, \quad \frac{\partial F_1}{\partial f}, \quad \frac{d}{dv}\left(\frac{\partial F_1}{\partial f'}\right)$$

and substituting into (17), we derive the following equation for the extremal

$$f = \sqrt{\frac{A}{B}} \cdot v^2 \cdot \sqrt{\frac{v + V_r}{v + 3V_r}} . \quad (36)$$

Assuming, as previously, that $v/V_r = P$, the equation of the extremal (36) can be represented in the form:

$$f = \sqrt{\frac{A}{3B}} \cdot V_r^2 \varphi^2 \sqrt{\frac{1+\varphi}{1+\frac{1}{3}\varphi}} . \quad (37)$$

If $\varphi \ll 1$, then, disregarding the terms with P^3 and the higher orders, we can write (37) as follows:

$$f = \sqrt{\frac{A}{3B}}\, V_z^2 \varphi^2 = \sqrt{\frac{A}{3B}}\, v^2 \tag{38}$$

Utilizing Eqs. (13) and (14), we can find simple analytical solutions for $t = t(v)$ and $L_a = L_a(v)$. In the extremal equation (37), we retain the terms with an accuracy up to ϕ^4. Under this assumption

$$f \simeq \sqrt{\frac{A}{3B}} \cdot v^2 \left(1 + \frac{1}{3}\frac{v}{V_z}\right) = V_z^2 \sqrt{\frac{A}{3B}} \left(\varphi^2 + \frac{1}{3}\varphi^3\right). \tag{39}$$

Knowing (39), we easily find that

$$dt = -\frac{V_z}{\sqrt{3AB}} \cdot \frac{6\varphi + 6\varphi^2 + \varphi^3}{4\varphi^2 + \frac{2}{3}\varphi^3 + \frac{1}{9}\varphi^4}\, d\varphi$$

hence, /27

$$t = \frac{V_z}{\sqrt{3AB}} \int_{\varphi}^{\varphi_0} \frac{6 + 6\varphi + \varphi^2}{4 + \frac{2}{3}\varphi + \frac{1}{9}\varphi^2} \frac{d\varphi}{\varphi}$$

with an accuracy up to P^3 the fraction

$$\frac{6 + 6\varphi + \varphi^2}{4 + \frac{2}{3}\varphi + \frac{1}{9}\varphi^2} = 1{,}5 + 1{,}25\varphi$$

and hence,

$$t = \frac{V_z}{\sqrt{3AB}} \cdot \left[1{,}25(\varphi_0 - \varphi) + 1{,}5 \ln \frac{\varphi_0}{\varphi}\right]. \tag{40}$$

Reverting to the variable v, we can write (40) in the form:

$$t = \frac{1}{\sqrt{3AB}} \cdot \left[1{,}25(v_0 - v) + 1{,}5 V_z \ln \frac{v_0}{v} \right]. \tag{41}$$

In a similar way, we can find $L_a = L_a(v)$; we can write the final equation as follows:

$$L_a = \frac{1}{\sqrt{3}\sqrt{AB}} \left[0{,}625(v_0^2 - v^2) + 1{,}5 V_z (v_0 - v) \right]. \tag{42}$$

Since

$$\frac{1}{\sqrt{AB}} = \frac{2K_{max}}{g},$$

while

$$\frac{v}{v_0} = \sqrt{f},$$

then Eqs. (41) and (42) can be written for the case $v = v_E$ in the following form, handy for calculation:

$$L_{a_{max}} = \frac{K_{max}}{g\sqrt{3}} \left[1{,}25 v_0^2 (1 - f_E) + 3 V_z v_0 (1 - \sqrt{f_E}) \right] \tag{43}$$

$$T_{at\ L_{a_{max}}} = \frac{K_{max}}{g\sqrt{3}} \left[2{,}5 v_0 (1 - \sqrt{f_E}) + 3 V_z \ln \frac{1}{\sqrt{f_E}} \right]. \tag{44}$$

Let us remark that direct comparison of Eqs (22) and (44), and also (23) and (43) is impossible, since the value of v_0 under optimal conditions, realizing the maximum L_a, is higher than the optimal conditions realizing the maximal flight duration.

In reality, from Eq. (38), it follows that /28

$$\left(v_0^2 \right)_{\text{at } L_{a\,max}} = \sqrt{3}\cdot\sqrt{\frac{B}{A}} = \frac{\sqrt{3}\, M_0 g}{\frac{1}{2} C_{y\,max}\,\rho\, S}\,.$$

However,

$$\frac{M_0 g}{\frac{1}{2} C_{y\,max}\,\rho\, S} = \left(v_0^2 \right)_{\text{at } T = T_{max}}\,.$$

Consequently,

$$\left(v_0 \right)_{\text{at } L_{a\,max}} = \sqrt[4]{3}\,\left(v_0 \right)_{\text{at } T_{max}}. \tag{45}$$

Thus, for the realization of the optimal horizontal flight of an aircraft powered by a rocket engine, it is necessary to impart an initial velocity (by carrier aircraft or carrier rocket about 32% higher than in the case of optimal flight for maximal duration.

Using Eq. (9) and the relationship $C_y = k\,\alpha$, we can easily show the angle of attack at which flight is accomplished for a maximal range; (α opt) at $L_{a_{max}}$ will be less than the angle of attack during flight for a maximal duration. The calculation has the form:

$$\left(\alpha_{opt} \right)_{\text{at } L_{a\,max}} = \left(\alpha_{opt} \right)_{\text{at } T_{max}} \sqrt{\frac{v + V_c}{v + 3V_c}} \tag{46}$$

using Eqs. (43) and (44), we can study the effect of low values of the basic parameters upon $L_{a_{max}}$ and (T) at $L_{a_{max}}$. The corresponding formulas can be obtained by the same procedure which was used for the calculation of T_{max}.

DEVELOPMENT OF THE IDEAS OF K. E. TSIOLKOVSKIY CONCERNING "ROCKET TRAINS" IN THE TRANSACTIONS OF SOVIET AND FOREIGN SCIENTISTS

Yu. A. Pobedonostsev and G. N. Nesterenko

"It is difficult to overestimate the importance of the suggestion of Konstantin Eduardovich concerning compound multi-stage rockets and rocket trains. In essence, this suggestion has opened the path for mankind into outer space". /29

S. P. Korolev

One of the most interesting sections in the creativity of Tsiolkovskiy was his study of compound multi-stage rockets and "rocket trains". The necessity of utilizing sectional rockets for attainment of cosmic speeds and the accomplishment of interplanetary flights was recognized by Tsiolkovskiy as the result of many years of diligent effort directed toward finding more practical ways for the emergence into outer space.

As is known, the proposals on the development of compound rockets had been advanced previously by other investigators [1, page 474]. The first mention of compound (multi-stage) rockets pertains probably to the 16th - 17th centuries, while in the 20th century, we know of the proposals made by R. Goddard, G. Oberth and others. However, it was specifically Tsiolkovskiy who first elaborated the scientific design bases and construction principles of multi-stage rockets.

For the first time, the concepts concerning the development of a compound rocket were expressed by him in 1926 in the revised and supplemented work "Investigation of World Space by Reaction Devices", where on the basis of the calculations made, Tsiolkovskiy arrived at a conclusion concerning the need to use a special launching stage, or as he calls it, an "earth rocket" for launching the space rocket. He writes: "Our space rocket should be mounted on another, earth rocket, or placed in it" [2, page 161].

As early as in this report, Konstantin Eduardovich gives his method for /30
the design and the first recommendations on the construction and use of multi-stage rockets.

The most complete reflections of the idea of developing multi-stage rockets are to be found in the works of Tsiolkovskiy "Cosmic Rocket Trains" (1929) and "Maximum Velocity of a Rocket" (1935). The last report is the tenth chapter of the incomplete monograph "Bases of the Construction of Gas Machines". Thus, Konstantin Eduardovich devoted the last years of his life to the study of multi-stage rockets. He considered these reports basically important for the creation and development of cosmonautics.

The scientist attempted to substantiate all his ideas and plans strictly scientifically and to place them on a practical basis. When the ideas of space flight with the aid of rockets began to penetrate into the consciousness of people, naturally there were many skeptics and pessimists who did not believe in the possibility of interplanetary flights. Proofs were necessary. Even Konstantin Eduardovich himself never was satisfied with general ideas. In the course of his entire life, he sought the most practical ways and convincing proofs for the possibility of rocket navigation.

Conducting the mathematical calculations for the single-stage cosmic rocket, Konstantin Eduardovich, before others, understood that in one jump, with the aid of one rocket, no matter how large, it would be difficult to overcome the barrier of Earth's gravitation. With the practically realizable specific thrusts of the rocket engines, it did not appear possible to design a rocket with the necessary ratio of masses of payload, design and fuel.

The calculation indicated that even at the theoretically maximal values of specific thrust, which could be provided by the rocket engines using chemical fuel, escape into an orbit in a single-stage model would require a rocket in which the weight of the fuel would have comprised 90-98% of its entire launch weight. Thus, only a few percent were left for the payload and the entire design of the rockets. Obviously, even in our days it is difficult to develop a single-stage cosmic rocket.

Also important is another reason, dictating not the necessity, but certainly the feasibility of the development of the multi-stage rockets. Other conditions being equal, a properly designed compound rocket placing a given payload into orbit as a rule, proves to be several times lighter than a single-stage rocket. We will attempt to illustrate graphically this truth, /31
(which is paradoxical at first glance) by using several examples.

In 1966, forty years had elapsed from the time of the appearance of the first ideas of Tsiolkovskiy concerning the multi-stage rocket. In the first decade of this period, only Tsiolkovskiy devoted attention to the question of the development of the theory of compound rockets. Even in the last 10 - 15 years, a profound mathematical development of the problem has taken place, when the questions of the calculation and design of compound rockets have become urgent practical problems in science and technology.

One of the basic problems of the theory of multi-stage rockets is the selection of the optimal ratios of the masses between the stages. In the course of the scientific-research work and the design developments of the rockets intended for placing artificial earth satellites (AES) into orbit, the question has arisen in practice concerning the scientifically based, most efficient division of masses (of weights) between the stages of multi-stage rockets [6, 7, 8]. These studies have indicated that multi-stage rockets are very sensitive to the selection of ratios between the stages. By the proper selection of these ratios, we can obtain the required rocket with the minimal launching weight, but otherwise, in case of incorrect distribution, the rocket will be too heavy, cumbersome and more expensive, while in the individual cases, a badly planned rocket in general, will not solve the formulated problem, i.e. it will not impart the required velocity to the payload, no matter how much we increase its launch weight.

In view of the urgency and, as we will indicate below, the relative complexity of the mathematical optimization of multi-stage rockets, in the second half of the 1950's, i.e. in the period of launching the first AES, more than twenty theoretical reports were published, devoted to the development of methods for optimizing multi-stage rockets [6, 8, 9]. Many interesting studies in this field have been made by foreign scientists [13,14, 15].

In this manner, by the early 1960's, the opinion had built up that the basic problems in the design of optimal multi-stage rockets had already been solved, that sufficiently rigorous mathematical methods had been developed, and that the ideas of the creation of "rocket trains" had been put in practice. However, it quickly became clear that the theoretical method of optimization developed in the 1950's cannot fully satisfy all of the practical requirements. The fact is that as basic initial data, in the 1950's in the optimization of the multi-stage rockets, we adopted certain specific values of the characteristics of the engines and the ratio of the masses of the con- /32 struction and fuel of the stages, i.e., the assumption was made that with changes in the weights of the stages in the process of choosing the optimal model, the specific parameters of the stages are held constant.

The application of theoretical methods of optimization yielded many interesting results confirming the high significance of the proper choice of the ratios between the weights of compound rocket stages. Thus, at that time, it was established that with theoretically optimal division of masses among the stages of the compound rocket, which placed the American satellite "Vanguard" into orbit, its launch weight could be reduced to less than half [8]. However, later on it was established by us that, in spite of all the complexity, optimization of compound rockets on the assumption of constancy of the individual stages' parameters with variation in their weights, provides results that are poorly suited for practice.

As an illustration of the nature of the problems with which it is necessary for researchers to struggle in the solution of the problems of optimizing multi-stage rockets, let us consider certain mathematical methods, assumptions and results obtained.

In the general case, the launch weight of a multi-stage rocket with division of the stages is composed of the weight of the payload and of the sum of the stages' weights:

$$G_0 = G_{pl} + \sum_{i=1}^{n} G_i^{st} \tag{1}$$

where G_o = the launching weight of the multi-stage rocket;

G_{pl} = the payload weight;

G_i^{st} = the weight of the i^{th} stage.

In the first approximation, each rocket stage can be characterized by two basic parameters; by the specific thrust of the engine R_i^{sp} and by the relative weight of the stage design, μ_i^k .

The total velocity - V_Σ, which the multi-stage rocket imparts to the payload is composed of the partial values of the velocities imparted by the separate stages:

$$V_\Sigma = \sum_{i=1}^{n} V_i \, . \tag{2}$$

In approximate calculations, it is assumed that the parameters of the stages remain constant with changes in weight, while the increments in the velocities being imparted by the stages, V_i and the total velocity V_Σ, respectively, include the actual increments in the velocity of the payload plus the losses for overcoming the attraction of the Earth's gravitational field, V_i^{gr}, and the atmospheric resistance V_i^a, i.e.: /33

$$V_i = V_i^\varphi + V_i^{gr} + V_i^\alpha . \tag{3}$$

Under these assumptions, Tsiolkovskiy's equation for the characteristic of the velocity can be written in the form:

$$V_i = gR_i^{sp} \cdot \ln\left(\frac{G_i^{st} + G_i^{pl}}{G_i^{K} + G_i^{pl}}\right) \qquad (4)$$

where G_i^k = weight of the structure i^{th} stage;

H_i^{pl} = the weight of the payload of the i^{th} stage.

Let us replace in Eq. (4) the weight of the stage structures by its total weight and the parameter μ_i^k ; after simple transformation we will obtain an expression for the weight of the stage through V_i, R_i^{sp} ; μ_i^k and G_i^{pl} :

$$G_i^{st} = G_i^{pl} \cdot \frac{e^{-\xi_i} - 1}{1 - \mu_i^K \cdot e^{-\xi_i}} \qquad (5)$$

where:

$$\xi_i = \frac{V_i}{gR_i^{sp}} .$$

Assuming that the first stage is the operating stage during launching, while the last stage is the one that places the actual payload into orbit, or brings it to the prescribed height and flight velocity, Eq. (5) for the i^{th} stage of an n staged rocket can be rewritten in the following form:

$$G_i^{st} = \left[G_{pl} + \sum_{i=n}^{n-i} G_i^{st}\right] \frac{e^{-\xi_i} - 1}{1 - \mu_i^K \cdot e^{-\xi_i}} \qquad (6)$$

where G_{pl} is the actual payload, i.e. the payload of the last stage.

If for a rocket with n stages we write the expressions of all the /34 the values G_i^{st} and substitute them in Eq. (1), after simple transformations we obtain the following expression for the launch weight of the entire rocket:

$$G_0 = G_{pl} \prod \left(\frac{1 - \mu_i^K}{e^{-\xi_i} - \mu_i^K} \right). \tag{7}$$

Since basically, two-, three- and four-stage rockets are of practical interest, let us write the expanded expression for the launch weight of a three-stage rocket:

$$G_0 = G_{pl} \left(\frac{1 - \mu_3^K}{e^{-\xi_3} - \mu_3^K} \right) \cdot \left(\frac{1 - \mu_2^K}{e^{-\xi_2} - \mu_2^K} \right) \cdot \left(\frac{1 - \mu_1^K}{e^{-\xi_1} - \mu_1^K} \right). \tag{8}$$

Usually the problem is formulated further as follows. Having derived the expression for the launch weight of the multi-stage rocket through the prescribed values of the payload weight and of specific parameters of the stages, it is necessary to distribute in such a way the total required acceleration and speed among the stages that we obtain the minimum launch weight of the rocket, i.e. in fact, the problem is reduced to seeking the minimum of functional dependence (8).

Let us first consider this problem in a simpler model; for a two-stage rocket, we will have:

$$G_0 = G_{pl} \left(\frac{1 - \mu_2^K}{e^{-\xi_2} - \mu_2^K} \right) \cdot \left(\frac{1 - \mu_1^K}{e^{-\xi_1} - \mu_1^K} \right) \tag{9}$$

where

$$\xi_1 = \frac{V_1}{g \cdot R_1^{sp}}; \quad \xi_2 = \frac{V_2}{g R_2^{sp}} = \frac{V_\Sigma - V_1}{g R_2^{sp}}.$$

Equation (9) contains only one independent variable, V_i. To simplify the differentiation of this expression for finding the minimum of the launch weight, let us reduce it to the form:

$$G_0 = \frac{G_{pl}\left[\left(1+\mu_1^{\kappa}\cdot\mu_2^{\kappa}\right)-\left(\mu_1^{\kappa}+\mu_2^{\kappa}\right)\right]}{\left[\left(e^{-(\xi_1+\xi_2)}+\mu_1^{\kappa}\cdot\mu_2^{\kappa}\right)-\left(\mu_1^{\kappa}\cdot e^{-\xi_2}+\mu_2^{\kappa}\cdot e^{-\xi_1}\right)\right]} . \tag{10}$$

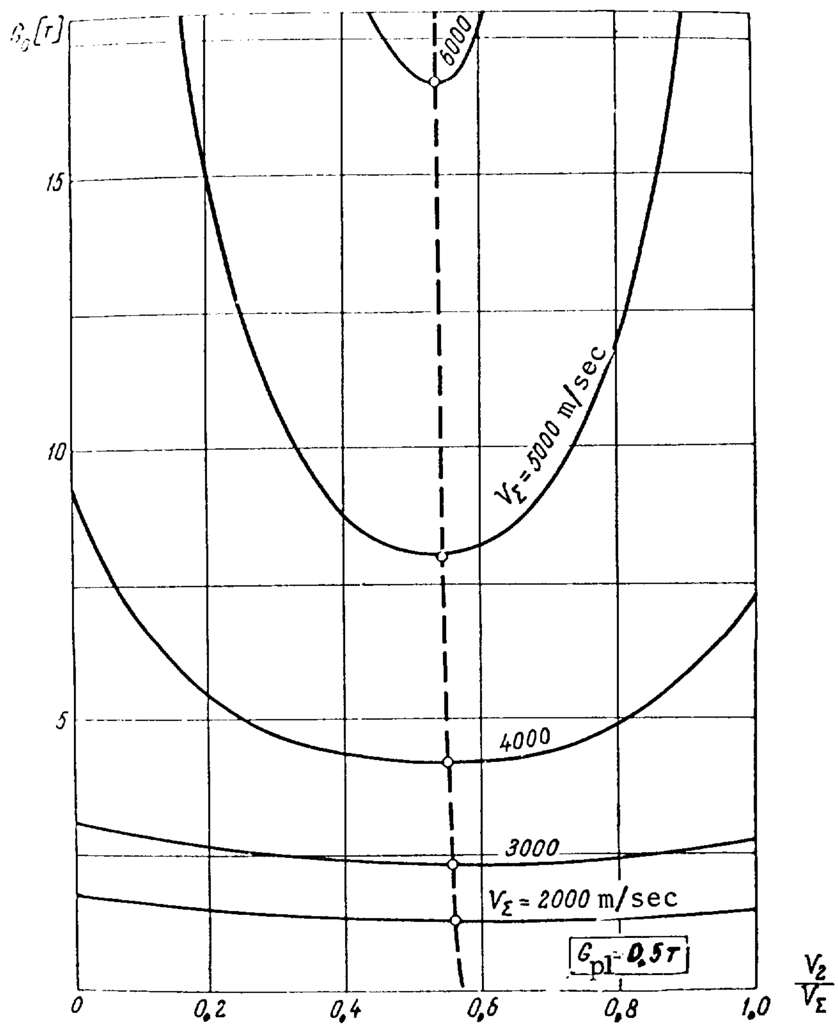

Fig. 1. Dependence of a Launch Weight of an Idealized Two-Stage Rocket Upon the Total Required Velocity of the Payload and the Distribution of this Velocity Among the Stages.

Now, since the numerator for the given problem proved to be constant, the minimum of the launch weight is obtained at the maximal value of the denominator. This signifies that the problem is reduced to solving for the maximum of the function: /36

$$\mathcal{F}(V_1) = \left[\left(e^{-(\xi_1+\xi_2)} + \mu_1^k \cdot \mu_2^k\right) - \left(\mu_1^k \cdot e^{-\xi_2} + \mu_2^k \cdot e^{-\xi_1}\right)\right]. \qquad (11)$$

Having equated the derivative of this function to zero, after transformation, we will derive the following condition for the maximum of the function (11) and, hence the minimum of the launch weight of the two-stage rocket:

$$1 - \left(\frac{\mu_1^k}{\mu_2^k}\right)\left(\frac{R_1^{sp}}{R_2^{sp}}\right) \cdot \exp\left(\frac{V_1}{gR_1^{sp}} - \frac{V_\Sigma - V_1}{gR_2^{sp}}\right) + \left(\frac{R_1^{sp} R_2^{sp}}{\mu_2^k \cdot R_2^{sp}}\right) \exp\left(\frac{V_1 - V_\Sigma}{gR_2^{sp}}\right) = 0. \qquad (12)$$

Since Eq. (12) is transcendental, it is impossible to obtain its solution relative to the desired optimal velocity V_1. This signifies that even in the simplest case of a two-stage rocket, it is necessary to resort to numerical or approximate graphic-analytical methods of solution. As an illustration of the effect of the distribution of the velocities (weights) between the stages of a two-stage rocket on its launch weight, in Fig. 1, we have shown several dependences of the launch weight upon the total required velocity of the payload and the distribution of this velocity between the rocket stages. For simplification, in the construction of the graph in Fig. 1, the following initial data are assumed: G_{pl} = 500 kg; R_1^{sp} = 240 kg sec/kg; R_2^{sp} = 245 kg sec/kg; $\mu_1^k = 0.14$; and $\mu_2^k = 0.13$.

An analysis of the graph indicates that at low values of the total required velocity of the payload, the conversion from a single-stage rocket, i.e. from $V_2/V_\Sigma = 0$ and $V_2/V_\Sigma = 1$ to the two-stage ($0 < V_2/V_\Sigma < 1$) yields practically no improvement in the launch weight. At relatively high values for V_Σ, the transition from a single to a multi-stage rocket and the correct distribution of the velocities among its stages acquire decisive importance.

Similar, only slightly more complex graphs, more precisely speaking nomograms, can be calculated and constructed for the optimal models of the distribution of velocities among the rockets having three and more stages.

After the analytical and graphic methods for the optimization of multi-stage rockets had basically been perfected and we had only to learn how to use them, it became clear that these methods disregard many factors which can change the results of the optimization quite appreciably. One of such factors is the SCALE factor, which consists in the influence of the so-called scale effect, specifically of the dimensions and weights of the stages upon their individual parameters. The scale effect is reflected quite noticeably in the structure-weight characteristics of the stages, such as the coefficient of filling with fuel and the relative weight of the stage structure μ^k, which was mentioned above. /38

The scale effect is a widely occurring phenomenon in nature and technology. In the field of aircraft and especially of rocket technology, it was noticed, and then scientifically substantiated, that, other conditions being equal, a large aircraft, engine, rocket, etc. has better specific parameters than a small one.

As an example, we have indicated in Fig. 2 how the relative weight of the structure of the rocket stages can vary with a change in the total weights in the process of selecting the optimal version. As is evident from this figure, the parameters of the stages can change very considerably. Disregarding the influence of the scale effect in the redistribution of the weights among the stages leads to a marked displacement along the horizontal lines μ^k (shown in the graph (Fig. 2) by a broken line), which in effect signifies a distortion of the actual situation in the process of theoretical optimization of multi-stage rockets.

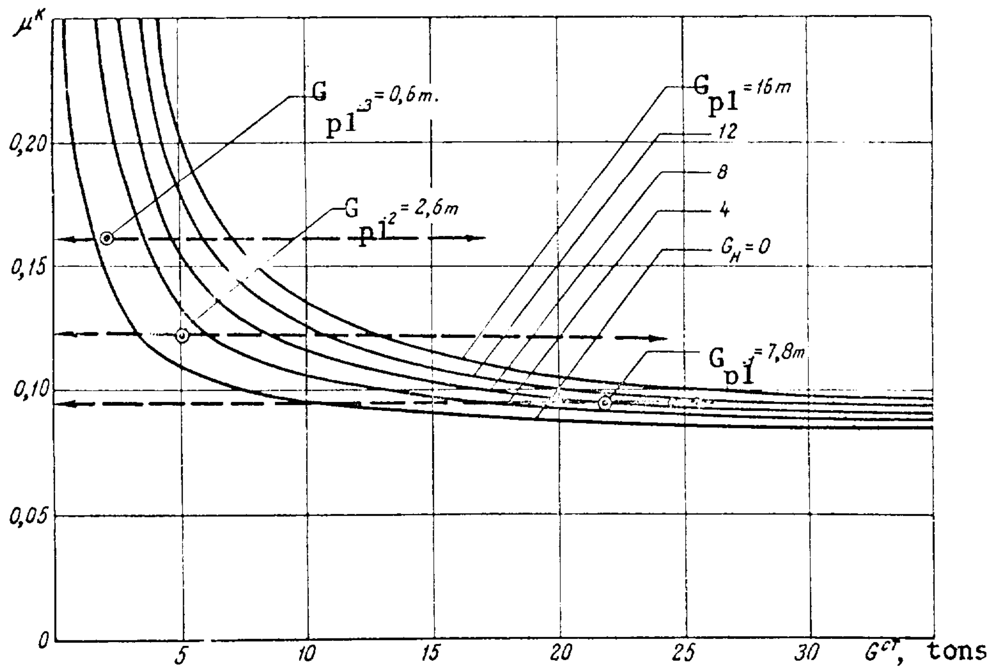

Fig. 2. Sample Graph of the Dependence of Relative Weight of Structure of a Compound Rocket Stage upon the Actual Weight and the Weight of Payload of Stage at a Given Thrust Arrangement.

For an illustration of the basic differences obtained in the optimization of multi-stage rockets with the assumption of constancy of specific parameters of the stages with a change in their weights as well as when this assumption is not made, let us consider two examples.

We have shown in Fig. 3 the curve of optimization of a two-stage rocket, similar to the curve of Fig. 1, but constructed with allowance for the influence of the scale effect upon the specific parameters of the stages. In the given example, the payload weight is assumed the same (500 kg), while the characteristics of the stages are assumed variable, about the same as in the actual rocket which was utilized for orbiting the "Vanguard" satellite.

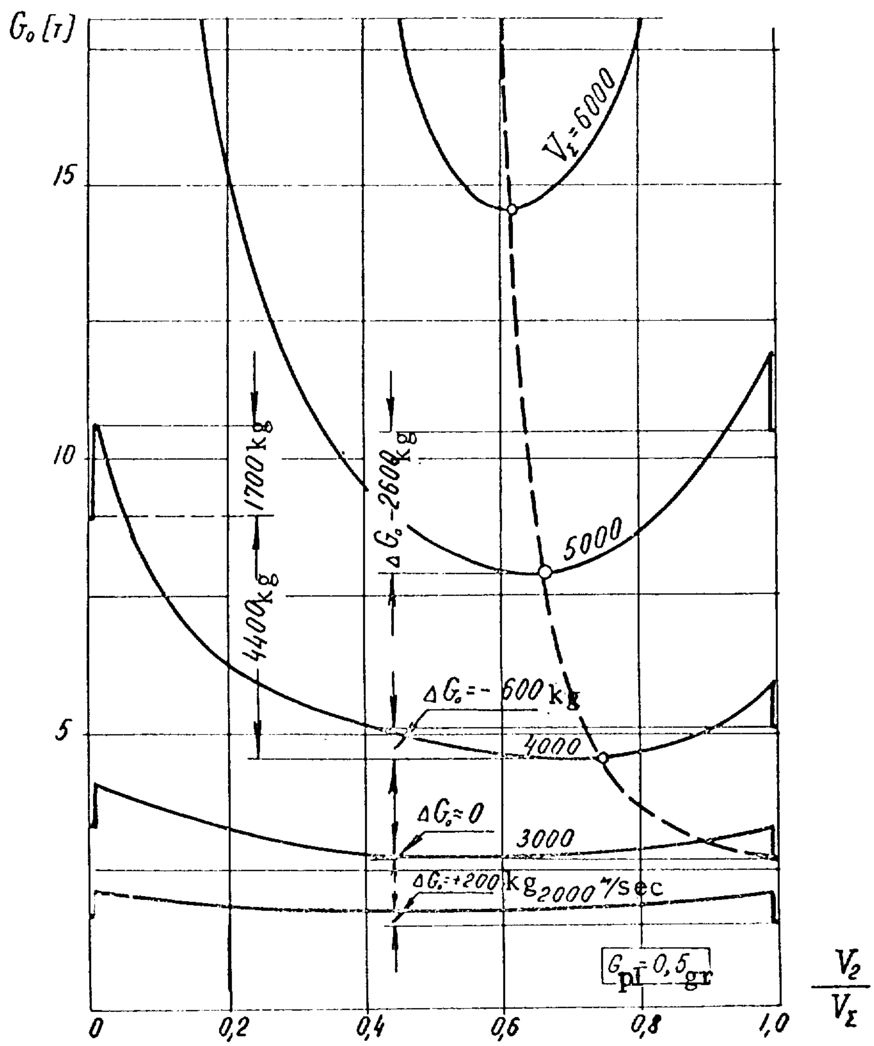

Fig. 3. Dependences of Take-Off Weights of Two-Stage Rockets Upon the Distribution of Velocities, Constructed with Allowance for the Scale Effect.

From an examination of the curve (Fig. 3), and a comparison of it with the earlier curve (Fig. 1), it is easy to see that consideration of the variability in the stages' specific parameters provides a more complete and more correct picture of the variation in the launch weight of the multi-stage rocket. In the graph (Fig. 3), we show more clearly the maximum velocities at which a single-stage rocket is practical, to what the transition from the /40 single-stage system ($V_2/V_\Sigma = 0$ and $V_2/V_\Sigma = 1$) to the two-stage system ($0 < V_2/V_\Sigma < 1$) leads, etc. Specifically, it is revealed that in the conversion from a single-stage to a two-stage version, initially we have a sudden increase in the take-off weight of the rocket, and then, in proportion to the increase in the weight of the added stage, we get a reduction in the complete take-off weight of the multi-stage rocket.

Based on the graph of Fig. 3, it is also possible to analyze another interesting question, namely with which values of V_Σ does the transition from a single-stage to a compound rocket not only yield no advantage in launch weight but even results in an increase as a result of the influence, once again, of the scale effect.

An even more graphic example is given in Fig. 4, where we have shown two nomograms for optimization (by various methods) of the three-stage American Vanguard rocket. On the left side of the graph, we have shown the results obtained in the calculations under the assumption of constancy of the stages' specific parameters with variation in their weights; on the right-hand side we have shown the results with allowance for the scale effects. The recommendations derived by the two methods in this case prove to be directly contradictory. In the calculations with the constant parameters, it seems that we must reduce basically the weight of the smallest, third stage. In the calculations with allowance for the influence of the scale factor upon the specific parameters of the stages, on the other hand, the weight of third stage must be appreciably increased, while owing to this, the weight of the first stage and the total take-off weight will decrease. In the final analysis, it was established that for that level of science and technology at which the Vanguard rocket was developed (1957 - 1958), it can be considered close to the optimal version.

The examples which we have cited are intended to illustrate only certain problems which the researchers encounter in studying "rocket trains", i.e. the multi-stage rockets of our days. Specifically, allowance for the influence of the scale effect and of other actual conditions determining the choice of the optimal rocket versions, complicates considerably the analytical solution of the problem with respect to their calculations. However, the derivation and substantiation of the actual dependences of the specific parameters of rockets upon their weight, the conditions of application, etc. constitute a fairly complex problem. In addition to the analytical relationships, it is necessary to utilize empirical statistical data, etc.

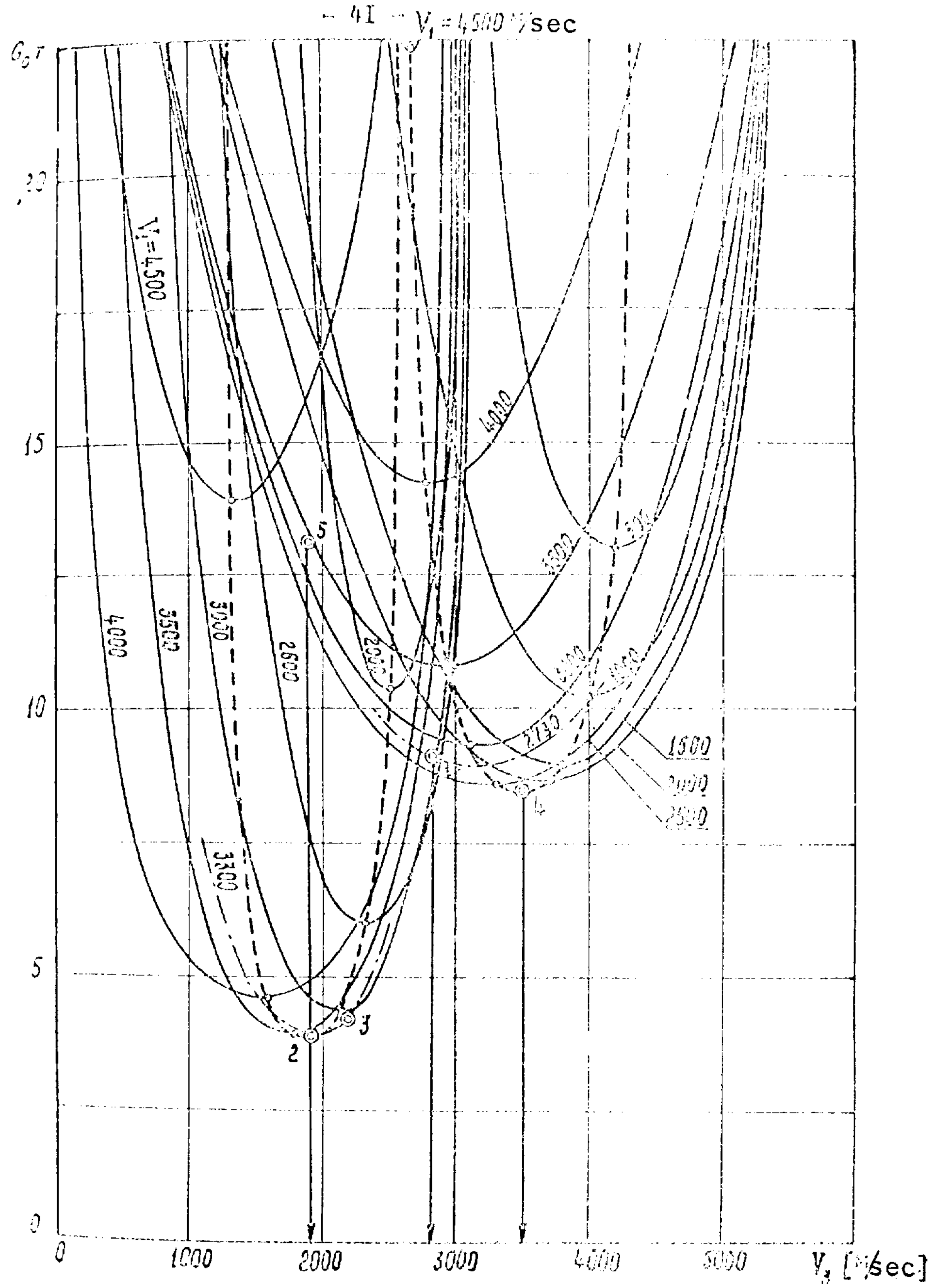

Fig. 4. Nomograms of the Optimization of the Three-Stage "Vanguard" Rocket by Two Different Methods. The Points Inserted in the Nomograms Signify: 1 - the version actually produced; 2, 3 - the theoretical "optimal" versions, obtained without allowance for the scale effect; 4 - the optimal version, with allowance for the scale effect; 5 - the theoretically "optimal" version-actually.

The usage of electronic computers for the mathematical modeling of multi-stage rockets, the choice of optimal versions of the distribution of weights, and the calculation of flight trajectories of multi-stage rockets has been quite fruitful. [16, 19, 24]. Computers permit us to "try out" hundreds and thousands of versions in advance, and to select only the best for practical realization. /42

The rocket technology of our days constitutes a shining example of the correctness of the basic precepts advanced by Tsiolkovskiy in respect to multi-stage rockets. All modern rockets for the launching of spacecraft and ICBMs are compound, multi-stage devices.

The methods of optimization of multi-stage rockets using weight alone do not satisfy modern scientists. In recent years, considerable attention has been diverted to the question of the selection and substantiation of more efficient criteria of optimization. Ever-increasing application is being found by criteria taking economics into account, permitting us to choose not only devices which are lightest in weight, but also the most inexpensive versions of rockets, because in the final analysis it is important to solve a problem at minimal expense, not at minimal weight. The investigations of recent years [20, 23, 24] indicate that the versions which are optimal from the viewpoint of the minimum weight and the minimum cost differ slightly from one another.

The effort to create ever more economical means for the delivery of payloads into earth orbits has constantly posed before science, both in the days of Tsiolkovskiy, and in our days, still another major problem, namely, that of the creation of so-called air-space vehicles, i.e. vehicles capable of using air, atmospheric oxygen in their engines at velocities all the way up to the space velocities. Scientists suggest that this can reduce the cost of launching payloads into orbit.

Several foreign scientists connect with the idea of the development of air-space flight vehicles the hope for the creation of single-stage space aircraft, capable of taking off from an airfield as a conventional aircraft, of accelerating with the aid of air-breathing jet engines to hypersonic velocities, and then entering into outer space by brief usage of rocket engines. Entering into orbit, the space aircraft accomplishes the mission of delivering cargos to space stations, servicing of various space vehicles, and then reenters the atmosphere and lands "as an aircraft" at an airfield.

The idea of the development of such vehicles is quite alluring, since at first glance it promises considerable economic advantages. To be sure, a multi-stage rocket and in general multi-stage aircraft are not ends in themselves, but a practical necessity of those areas of application for those cases where the problem cannot be solved by a single-stage version. Everywhere they can, the designers are striving to avoid the compound, multi-stage system of aircraft, since it is more complicated and less reliable. Therefore, in modern science and technology, two opposing tendencies are competing /43 constantly; the effort to make a vehicle lighter and cheaper, on the one hand, and sufficiently reliable and simple, on the other hand.

Proceeding to the development of a space rocket or an aircraft, first of all, we check the possibility of its development in a simple single-stage version. As it was with the first versions of the Tsiolkovskiy space rocket, it is presently occurring with the plans for multipurpose air-space vehicles.

However, the preliminary studies already made by a number of foreign firms have shown that single-stage versions of air-space vehicles are difficult to design and scarcely have practical significance. Specifically, the German Belkow firm arrived at this conclusion; this firm conducted preliminary planning on several versions of space aircraft [25].

Thus, in our time also, the basic principles of the development and use of the multi-stage vehicles established by Tsiolkovskiy in his study about "rocket trains" will obviously find new application in the creation of winged aircraft for space purposes, namely multi-stage space aircraft.

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WORKS OF K. E. TSIOLKOVSKIY IN THE FIELD OF TECHNOLOGY AND THEIR MODERN IMPORTANCE /46

A. S. Fedorov

The remarkable works of our outstanding countryman, Konstantin Eduardovich Tsiolkovskiy, in the field of rocket technology, the conquest of outer space and of dirigible construction are well-known. They form a stable foundation for the development of the theory and practice of rocket flight, for the design of marvelous space vehicles, furrowing the expanses of the universe. In our days, the words of the brilliant scientist have become prophetic: "Mankind will not remain eternally on Earth, but in the race for light and space, initially he will timidly penetrate beyond the limits of the atmosphere, and then he will conquer the entire solar system".

It is difficult to overestimate the importance of the tremendous contribution which Tsiolkovskiy made to the development of the theory of reactive propulsion, in the substantiation of the possibility of interplanetary travel, and the solution of many practical problems associated with the development of rockets, of ultrafast aircraft flying in the upper layers of the atmosphere, of dirigibles and other vehicles. Tsiolkovskiy was a man of many gifts. He was interested in an unbelievable range of scientific and engineering problems. His inventive mind was continuously working on the improvement of much of that which surrounds man in his life, in his work activity. All of the content of the life of the scientist, all of his scientific creativity was determined by his unflagging concern for the happiness of people, concerning the progress of mankind, the effort to develop what was new, which would ease the burden of work and beautify life. "The basic motive of my life," wrote Tsiolkovskiy, "is to make something useful for people, not to live my life in vain, and to move mankind ahead even if only a little. This is why I have been interested in that which has given me neither bread nor power. However, I hope that my works, perhaps quickly, and perhaps in the remote future will give to society mountains of bread and limitless power."

In the scientific heritage of Tsiolkovskiy, there are dozens of reports /47
devoted to the most diversified questions of astronomy, biology, and technology. This once again emphasizes the unique versatility of the scientist, and the unbelievably broad spectrum of his scientific interest. Many of these reports were published in the fourth volume of his collected works. These works are diversified in subject, in style of presentation, and level of presentation. However, they combine the fervent effort of the author to understand better the surrounding world, to lift the veil to the unknown, and to place new forces of nature at the service of people, "to move mankind ahead even if only a little".

Tsiolkovskiy believed profoundly in the power of science and in the progress of technology. In a series of articles, begun as early as 1915 and devoted to a forecast of the future of Earth and of mankind, the scientist convincingly proved the ever-growing role of science and technology in subjecting to mankind the elemental forces of nature and in the reconstruction of human society itself.

"Parallely, or simultaneously," Tsiolkovskiy wrote in 1915, "they will develop: man, science and technology. From the effect of these three, the appearance of the Earth will be transformed. Let us begin with technical progress. First of all, we will achieve the improvement of that which is now being done. The output of the worker will be increased by hundreds of times with the aid of machines. His work in all areas will be made completely safe, not harmful for his health, and will even be pleasant and interesting. The length of the work day will be reduced to 4.6 hours. The remaining time will be devoted to free, voluntary efforts, to creativity, recreation, science, dreams..." The scientist was speaking of the new deep mine shafts, the utilization of the internal heat of the Earth, of new materials, the ultrahard, light, nonoxidizing and refractory ones. He was visualizing the new methods for obtaining unusually high and unusually low temperatures which will find broad application in the national economy. The scientist was predicting an ever-increasing exploitation by man and of the wealth of the seas and oceans, and many other possibilities. Now, we can observe how true these predictions have become, how much man has achieved both in the development of new materials, in the practical use of deep cold and of superhigh temperatures, and in the conquest of the riches in the seas and oceans.

The published works of Tsiolkovskiy on pressing individual questions of technology can be divided into four groups. In the first, we include his articles on high-speed ground transport. The second group of reports is associated with the exploitation of the energy from ocean waves and with the study of the depths of the sea. The third group includes his reports on the design of air-blowing devices and internal combustion engines. Finally, the fourth group of studies is represented by articles on the conquest of deserts /48 and the practical use of solar energy. It is typical that most of these reports were developed in the last decade of the scientist's life, i.e. in the last half of the 1920s and the first half of the 1930s. Several of them were even published then by Tsiolkovskiy in scientific and scientific-popular journals, or were published by the author in Kaluga in small pamphlets. Many reports were kept for a long time in the official archives and were published quite recently.

Decades separate us from those days when these studies, deliberated to the finest details by the author, were first placed on paper. These have been years of powerful development of the creative forces of our people, years of the tempestuous development of science and technology, However, these reports by Tsiolkovskiy, his studies even on the most specialized, unique questions have not lost their practical importance even now. Not just individual scientists, but large scientific groups, entire laboratories and institutes, equipped with modern scientific-research facilities, are continuing the studies of Tsiolkovskiy in the area of the use of solar energy, the subjugation of the energy of the ocean, and in the development of high-speed ground transportation.

In his writings, even on the most specialized questions of technology, Tsiolkovskiy appears to us as a daring innovator, believing deeply in the creativity of human intelligence and in the power of science. All of his technical and scientific ideas comprised the result of indefatigable quests, deep thoughts, expanded by precise calculations and numerous experiments. In very brief words, Tsiolkovskiy himself characterized his creative method: "Initially, they proceed inevitably; thought, fantasy, narrative; they are followed by scientific design, and finally the performance crowns the thought". All of the reports by Tsiolkovskiy, the remarkable scientist and inventor, comprise an example of the profound synthesis of theory and experiment. After a careful and thorough deliberation and precise mathematical calculations, they are embodied in mockups and models, the first version of the future improved technical devices.

K. E. Tsiolkovskiy was attracted by the idea of high-speed transportation. He devoted several articles developed in detail on this subject. In /49 them, the scientist remains true to himself: the technical concepts are checked by precise calculations and reinforced by experiments; in any case, this is done within the limits of those small material resources which were available at that time to the researcher.

Let us dwell first of all, on the actual idea placed at the basis of the Tsiolkovskiy papers regarding high-speed ground transport. Only in our time can we evaluate fully its unusual depth, novelty and tremendous practical importance. In the years when operating speeds of railway transport of the order of 50 - 60 kilometers per hour were considered near the limit, while the flight of an aircraft at 250 - 300 km was regarded as a tremendous advance in technology, Tsiolkovskiy dreamed of supersonic speeds not only in space but also in the Earth's atmosphere. He foresaw the possibility of a sharp increase in the speeds of gound transport.

In what ways can we obtain a sharp increase in the speeds of transport media on Earth? Tsiolkovskiy provides an exact answer to this question: only with the application of a basically new method, of new engineering concepts. They should be means of transport not moving on a road but floating over it. A resiliant and elastic air cushion should separate the high-speed vehicle from the road.

After performing the mathematical calculations reinforcing the validity of his technical idea, Tsiolkovskiy as always was also thinking of its practical fulfillment. He proposed various versions of high-speed vehicles, justified their dimensions, form, and considered the nature of the road. As early as his first report on this topic "Air Resistance and the Express Train" published in Kaluga in 1927, he spoke convincingly of that time when trains utilizing the force of inertia would "jump across all rivers, abysses and mountains of any size", when "it will be unnecessary to have bridges, tunnels or other large ground and mountain facilities". The scientist was dreaming of that time when only a half-hour ride by train would separate Moscow from Leningrad, and it would only take 10 hours to travel from the pole to the equator, and not on an airplane (this is possible already in our time), but in the care of a high-speed surface express train.

The scientist also returns to this same idea of an air cushion in later reports devoted to high-speed surface transport. In an interesting report "General Conditions of Transport", written in January 1934, and first published in the fourth volume of his collected works, Tsiolkovskiy actually considers even the specific details of the devices suggested by him, i.e. the type of engine, the form and design of car, the arrangement of the right-of-way, the profile of the track, etc. /50

The most important and interesting in his reports on ground transport is his basically new idea of an air cushion, so broadly formulated and scientifically based by the outstanding scientist for the first time several decades ago. Now, this idea is close to its practical conversion to reality. Experimental designs have already been developed of devices which are separated from the road by a resiliant cushion of compressed air. Fast passenger vessels of the *"Raketa"* and *"Meteor"* type are already travelling over our lakes and rivers at high speed. Their lower surfaces submerge only a few centimeters. The day is not far off when vessels will also hover above the water, separated from it by the same air cushion, and they will be able to move easily across sandbanks, rapids and manmade structures.

Another group of reports by Tsiolkovskiy leads us into the depths of the seas. The importance of the study of the submarine world was stressed repeatedly by the scientist. Even during the life of Tsiolkovskiy, mankind had handily succeeded in the conquest of the sea and ocean depths. "The sunken fiery vessels" of the late Middle Ages opened the road for the era of submarines, which as early as the 1930s had reached depths of 100 and more meters. The bathyspheres also descended into the ocean for hundreds of meters; there were massive steel globes for the investigators of the depths. However, the diving depth was limited at that time by many factors, primarily by the strength of the materials of which the devices for underwater studies were made.

Tsiolkovskiy, with the caution typical of him, designed various versions of underwater scientific laboratories and concluded that even with the currently available materials, the diving depth of a bathysphere could reach not hundreds of meters, but several kilometers, without any danger to the researcher's life. The further development of the bathysphere design fully confirmed this prediction of the scientist. In our time, with the aid of bathyspheres, we can reach practically the deepest levels in the world ocean. Indeed, quite recently the Swiss scientist Jacques Piccard submerged in his deep water bathyscaph *"Trieste"* to a depth of 10,910 meters, having reached the bottom of the Marianas Trench, one of the deepest points on our planet.

Of great interest is the Tsiolkovskiy report devoted to the practical use of the energy of ocean waves. This subject, as well as the use of the potential energy reserves developing from the tidal ebb and flow, has intrigued humanity for centuries, and even in our days it is still far from having received a broad practical solution. The scientist proposed very simple designs capable of converting the oscillatory motions of the waves into the rotation of a flywheel in a novel power plant. However, even in this case, as always, Tsiolkovskiy formulated and solved a complex problem. He was interested not only in using the energy in the waves, but also in subduing them. It is not by chance that the power installations operating from the force of waves were combined by him into a unified concept with a wavebreaker device, subduing the wave action, protecting the shores and the various structures from the destructive force of the surf. /51

A number of reports by Tsiolkovskiy are devoted to air-blowing devices. The interest of the scientist in these questions is by no means fortuitous. He always lived with those interests with which our country and our people lived. Untiringly working on the problems of science of the future, which included in his lifetime, the ideas of flights into space, Tsiolkovskiy always held in the field of his vision the pressing current problems. They were no less grandiose.

The last decade of his life coincided with the beginning of the titanic task of the industrialization of the USSR, launched by the Communist Party. These were the years of the first Five Year Plans, when the industrial base of socialism was being laid, and the first giants of metallurgy, machine construction, and power engineering were being created. Tremendous quantities of compressed air were necessary everywhere, both to power the metallurgical facilities and to activate the pneumatic devices in the various branches of industry. However, in our country at that time we had not yet organized the production of modern air-blowing machines of the turbocompressor type, including axial multi-stage compressors. The studies by Tsiolkovskiy in this field, especially his article "The Gas Compressor and Its Design", for that time were uniquely applicable and have not lost importance to our day. They are characterized by clarity, purposefulness and universality, i.e. the possibility of broad utilization in the solution of practical problems under the most diverse production conditions.

The studies of Tsiolkovskiy on technology contain a series of articles on the exploitation of the deserts and the use of solar energy. More than three decades have elapsed since the first publication of these reports. But has the reality of these studies decreased in that time? No, it has not; /52
rather, it has increased greatly.

In our country, the invasion of the desert is being accomplished on a broad scale. Already, many hundreds of thousands of hectares of sun-scorched earth have been converted to blooming gardens, vineyards, boundless fields, yielding bountiful crops of "white gold", namely cotton. Of course, the decisive role in the conquest of the desert is played by water. Only by irrigation, the digging of canals and hydraulic systems, have we managed to convert, e.g. a considerable part of the Golodnaya Steppe in Uzbekistan, to a fruitful area, the "Land of Roses", as the Uzbeks affectionately call it. These studies were launched by the Soviet government even in Tsiolkovskiy's time and are continuing in our days on a greatly expanded scale.

Tsiolkovskiy was interested in the various questions associated with the reclamation of the desert. He tried to use, for the purpose of irrigation, the moisture in the atmosphere, by way of its condensation in special "air columns" and the collection of artificial ground water. In both cases, he made the necessary calculations and proposed clever design solutions.

The attention of the scientist was also drawn to the question of the direct use of solar energy. In his article "The Sun and the Conquest of the Deserts", he dwells on many aspects of the use of solar energy. Here, he also discussed the control of temperature in houses, the arrangement of kitchens, baths and laundries, and the obtainment of steam for power purposes, the melting of metals, and many other aspects. In this connection, Tsiolkovskiy suggests the design of a number of heliotechnical devices, i.e. of round mirrors and boilers which prior to that had been tested repeatedly by him in Kaluga and had yielded encouraging results.

In the postwar years, the scale of experimental studies on applied solar energy had expanded considerably, especially in the southern regions of the Soviet Union. In the solar facilities, we obtain steam, ice and fresh water. With them, we heat houses, greenhouses, and we melt metals. The time is at hand when all of these test studies will begin to be adopted widely in practice. To a considerable degree, man will use his powerful and most economical source of energy, the Sun.

Tsiolkovskiy foresaw the vast role of solar power engineering in the immediate future. He predicted sagely that especially wide application of solar machines will be found in space, "when man will conquer circumsolar /53
space and will build living facilities near the planets or near the asteroids". Evidently, this time is not far off. Even now, artificial Earth satellites and the automatic space stations, sent to remote planets, are equipped with solar batteries, supplying power to the radio transmitters and other devices on these space vehicles.

What has been said above does not exhaust the heritage of Tsiolkovskiy in the area of technology and inventions. The manuscripts of the scientist and his articles publised many years ago reveal the diversity of his inventive ideas. We find there a description of a steam-gas engine and of an original gyroplane, similar to a flying wing (tailless airplane), a new design of a typewriter and devices for interplanetary communication, a home air conditioner and many other (both simple and complex) technical devices for use in industry, agriculture, transport, communication and for household purposes.

It has been more than 30 years since the death of Tsiolkovskiy. These have been years of considerable progress of science and technology, years of the fruition of many ideas of the remarkable scientist and inventor. The Soviet people, equipped with most progressive science, are working untiringly in the transformation of the nature of their country, in the conquest (in the interest of all mankind) of the cosmic vastness of the Universe and of the oceanic depths of our planet. As formerly, the works of Tsiolkovskiy truly serve scientific progress, and his glorious life inspires us to give devoted service to science and to our homeland.

THIRTIETH ANNIVERSARY OF THE HOUSE-MUSEUM OF K. E. TSIOLKOVSKIY /54

I. S. Korochentsev

On the eve of the Fiftieth Anniversary of Great October Socialist Revolution, the Memorial House-Museum of K. E. Tsiolkovskiy is celebrating its thirtieth anniversary. It is with a special feeling of excitement and pride that we now hear the words of the great scientist, addressed to the Central Committee of the Communist Party: "Before the revolution, my dream could not be realized. Only the October Revolution brought recognition to the work of this self-educated person". We might say that the most convincing and graphic proof of this recognition is the creation of his Memorial Museum, a valuable relic of the Soviet people.

The Memorial House-Museum was opened in a dwelling in which the scientist had lived for 29 years. This house, is associated with the extensive and extremely fruitful period of Tsiolkovskiy's scientific activity.

Konstantin Eduardovich bought this house in May 1904. At that time, it was a single-story house. In the Spring of 1908, a severe flood occurred. According to the memory of old-timers, during the night of April 2 the water began to rise quickly and flooded the house. Konstantin Eduardovich moved his family to a neighbor's house and he personally remained with his books, instruments and manuscripts in the garret of his own house. He was brought food in a boat and it was handed to him through a small window in the garret.

In the Summer of 1908, according to Konstantin Eduardovich's plan, an attic and a porch were added to the house,while the first story had a woodshed attached to it. The attic, the famous "small room at the top", was the office of Konstantin Eduardovich in which we have preserved the conditions which existed during the life of the scientist. Here, we have kept his instruments, devices, and the books which he used.

On a large porch with windows across an entire wall, Konstantin Eduard- /55
ovich set up his workshop. Here we have also preserved all the machinery: the lathe, the bench, the anvil and other objects. The porch had passages to two roofs, which the scientist used as experimental areas. Here he conducted simple aerodynamic tests; from here he observed the flight of birds, and enjoyed watching the starlit sky at night.

The rooms of the lower story of the Museum have been provided with exhibits, acquainting the visitors with the scientific-technical ideas of Tsiolkovskiy, and also with the attainments of modern science and technology

[1] "Pravda," 17 Sept. 1935, No. 257.

in the field of air navigation, aviation and astronautics. This explained the fact that, in contrast to the unchanged memorial conditions of the upper story, the exhibition of the scientific-technical section has changed basically several times during the existence of the museum, having gradually been updated with new exhibits.

Let us present a brief history of the Museum, and indicate its scientific and publicity work.

In the Autumn of 1933, the Tsiolkovskiy family moved to a new, large, and comfortable home, which was provided to the scientist by a decision of the Kaluga Municipal Council in connection with the seventy-fifth anniversary of Tsiolkovskiy's birth. In 1936, the Kaluga regional executive committee adopted a resolution concerning the establishment of the Memorial Museum (unfortunately, the original documents concerning this matter were lost during the German fascist occupation of Kaluga during World War II from 1941 - 1945). In the organization of the museum, considerable practical assistance was exerted by the party organization and the community of Kaluga.

The museum was opened on the day of the first anniversary of the death of Konstantin Eduardovich, 19 September 1936. More than 1,000 visitors were received on the opening day of the Memorial House.

Before the German fascist occupation, the museum exhibits were packed into boxes for evacuation but this was not accomplished. On 12 Oct. 1941, Kaluga was occupied by the Nazis. On the following day, 14 signal corpsmen were billeted in the museum with a German officer. Three rooms of the lower story were used for living quarters, and everything which the invaders considered surplus was tossed into the yard. The area which is now taken up with the exhibit "Air Navigation and Aviation" was used as a supply area. The fascist invaders used the porch for a henhouse. Here they kept dozens of chickens which had been stolen from the population. They cut up meat on the /56
scientist's desk. The stove in the kitchen was kept going for days on end. The soldiers burned all of the window frames, broke the gates, garden benches and canopy walls for firewood. An irreplaceable loss was the destruction of the memorabilia: the bookshelves, the handmade wooden bed, wooden corrugated shafts. Of the numerous wooden objects which had been cut by the scientist, for aerodynamic tests only seven remained whole by chance; all the others had been thrown into the fire. Unique details of a typewriter designed by Tsiolkovskiy were lost. The tin ear pieces of Tsiolkovskiy were used by the Nazis as funnels for gasoline. The invaders broke the plastic sculptured bust of Tsiolskovskiy, stole his microscope, broke the wind tunnel and damaged many other exhibits.

A report concerning the loss inflicted by the German invaders indicated the cost of what had been destroyed, broken or damaged. However, in reality the loss inflicted by the Nazi barbarians cannot be reckoned in rubles, no matter how high the sum might be.

On the night of 30 December 1941, after fierce fighting, the Soviet troops occupied the southern and southwestern suburbs of Kaluga and, having extended their operations, liberated the city from the occupation forces. The Hitlerites who had been billeted in the museum hurriedly fled, not having time to destroy the museum building.

Soon after the liberation of Kaluga, restoration work started in the museum. On 8 March 1942, the museum was opened for inspection. The first entry in the book of comments was laconic and expressive: "It is pleasant to look at the Tsiolkovskiy House-Museum and to see everything which has been retained. One is seized by a feeling of hatred and contempt for the wild barbarism of the Hitlerite Army".

Many other entries made then and in the later years of the Great Patriotic War, give evidence of the patriotic feelings evoked by a visit to the old house at the edge of the ancient Russian city.

During 10 months of the harsh war year of 1942, the museum was visited by over 3,000 people, the major part of whom were Red Army troops. In the difficult war years, the museum continued to carry on publicity work, gradually expanding its mass activity.

A year of great change in the operation of the museum was 1957, when on 17 September the city's population and the museum heralded the 100th anniversary of Tsiolkovskiy's birthday. On this day, the scientific-technical section of the museum received from the USSR Academy of Sciences a new exhibit prepared at the initiative of Academician Sergey Pavlovich Korolev. On /57
17 September, Sergey Pavlovich visited the museum, and in the evening he attended the theater for the triumphal meeting devoted to the 100th jubilee year of the Soviet scientist.

On 4 October 1957, when, with its radio beeps, the Soviet artificial satellite notified the people of the dawn of a new space age, a new page in the history of mankind was opened. The general triumphant interest in astronautics and in its founder, Konstantin Eduardovich Tsiolkovskiy, brought thousands of visitors to the museum from all corners of our vast country. The attendance at the museum rose sharply and since then has continued to grow without pause.

The Soviet scientists, in cooperation with the engineers and technicians, have successfully brought to life the ideas of Tsiolkovskiy, and very quickly difficulty arose in arranging the exhibits depicting this triumphant conquest of space. In April 1958, the collection of the museum was expanded by unique exhibits, artificial Earth satellites and a duplicate of the sputnik which had been put into orbit. Many new and remarkable exhibits appeared.

Naturally, the question arose of the need for expanding the scope of the museum's activity in all directions. This concept was expressed with maximum clarity in the book of comments and suggestions by Lev Aleksandrovich Druzhkin, who visited the museum on 19 November 1958. In this book, he wrote:

"The museum leaves an excellent impression. But one can by no means stop there. It is necessary to expand the museum, or to build a new one, where we can present a more extensive exhibit of the works of Tsiolkovskiy in the various areas of science, and not merely in the fields of jet technology and astronautics".

On 8 April 1959, the newspaper *Literature and Life* published a letter to the editor "To Create a Museum for the Conquest of Space". This letter was signed by the Vice President of the USSR Academy of Sciences, Academician I. P. Bardin, and Academicians A. A. Blagonravov, L. I. Sedove, A. N.Tupolev, Dr. of Technical Sciences P. K. Oshchepkov, Candidate of Physico-Mathematical Sciences L. A. Druzhkin, and Candidate of Technical Sciences I. I. Gvay.

In the letter, reference is made to the need for the development of a State Museum in Kaluga for the history of jet technology and astronautics, which could justifiably be given the name of the great scientist, Konstantin Eduardovich Tsiolkovskiy.

This letter comprised the first exhortation in the press for the organ- /58
ization of a new, larger museum. The remarks by the most outstanding Soviet scientists had far-reaching consequences.

As a result, in May 1960 a resolution was adopted for the construction of the K. E. Tsiolkovskiy State Museum in Kaluga and the restoration of the House-Museum. On the basis of this resolution, an open competition was announced for a plan for the building of the K. E. Tsiolkovskiy State Museum in Kaluga.

In the competition, more than 230 plans were presented, from more than 30 cities of the Soviet Union. The popular name of Tsiolkovskiy attracted not only a large quantity but also a wide diversity of forms in the proposed architecture of the building for the new museum. Public hearings and animated discussions of the plan were held in Moscow and Kaluga. First prize in the competition was given to a plan called "Kaluga"; this plan had been formulated by architects B. G. Barkhin, V. A. Strogiy, K. D. Fomin, N. G. Orlova and Ye. I. Kireyev.

The contest was the first practical step toward the development of a new museum. At the same time, measures were adopted for the preservation of the Memorial House-Museum; specifically in 1960, steps were taken to restore the museum building. From mid-August to the end of the year, the Memorial House was opened for visitation, but a considerable part of the collection was transferred to the Kaluga regional lore museum and was opened for examination. The personal belongings of Konstantin Eduardovich, his instruments and devices were displayed. The following themes were shown: "Metal Dirigible", "Airplane", "Autopilot", the "Space Rocket of Tsiolkovskiy", "The Ideas of Tsiolkovskiy are being converted to reality", and others. A philatelic exhibit was opened devoted to the memory of the great scientist. The museum issued an artistic cover bearing the portrait of Konstantin Eduardovich.

This cover received great recognition among collectors in our country and even became known abroad.

The collectors remember well the second cover, issued by the museum somewhat later, with a picture of the automatic spacecraft photographing the moon and the imprint "First Anniversary of Tsiolkovskiy Crater".

On 12 April 1961, the world learned by radio of the first flight of man into space. Yuriy Alekseyevich Gagarin, having accomplished a flight on the spacecraft "Vostok", brought the vision of Tsiolkovskiy to reality.

On 13 June 1961, in the area adjoining Tsiolkovskiy Park, the triumphant cornerstone-laying ceremony of the State Museum was held. The first stone /59
in the foundation of the building was laid by the first astronaut of the world, Hero of the Soviet Union Yuriy Alekseyevich Gagarin. The Kaluga residents remember well this triumphant and joyful day of meeting the space hero.

In September 1961, a resolution was adopted concerning the transfer of the museum to the authority of the RSFSR Ministry of Culture, which opened broad possibilities for expanding the museum's activity.

In early 1962, the "Guidebook to the Museum" was published (first edition). The attendance and the popular activity increased incessantly. A learned Council of the museum was organized, in which there were specialists, working on air navigation, aviation, rocketry and astronautics, as well as people in various specialties actively extending assistance to the museum in the work. The staff of the Learned Council included citizens of Moscow and Kaluga. Owing to this, the first meetings on the Learned Council were held separately in Moscow and Kaluga. The first meeting was held on 25 December 1962 in Moscow. Questions were examined connected with the development of a topical plan for the exhibition of the future K. E. Tsiolkovskiy Museum. The landmarks were noted in the very extensive and responsible work, which the group of museum co-workers had to accomplish.

One should particularly note the extensive work completed by the group of scientific co-workers at the museum in 1963 on the development of a thematic-exhibition plan, and the development at the museum of a lecture group of the *"Znaniye"* Society. This society included six museum workers as members. They prepared and presented the following lectures: "Life and Activity of K. E. Tsiolkovskiy", "Scientific Heritage of Tsiolkovskiy", "Our Space Roads", "The First Artificial Earth Satellites". By special request, they prepared the following special dialogues: "Tsiolkovskiy and Children", "The Formula of Tsiolkovskiy", "Recollections of Tsiolkovskiy" and many others. Some of these lectures included slides, movie films, and illustrated material.

On the occasion of the Day of Astronautics, the collection of the museum was augmented by models of the first Soviet liquid fuel rockets "09", "GIRD-10", "06", and "07".

In September 1963, in cooperation with the minicipal department of culture and movie theaters of Kaluga, a movie festival was held with the films about Tsiolkovskiy and the conquest of space. The display collection of the museum was augmented by temporary displays from the holdings. During the /60
year, 11 such displays were presented.

In 1964, development (begun in 1963) was completed of the thematic and topical-display plans of the K. E. Tsiolkovskiy Memorial House-Museum: a detailed description was made of the collection by halls, as was a list of the displays. The topical-display plan, with additions and comments, was approved by the Learned Council of the museum in December 1964.

On astronautics day in 1964, the triumph of Tsiolkovskiy's ideas took the form of a great holiday. At a triumphant evening in the regional theater, the Kaluga citizens met astronaut P. R. Popovich. The next day, in the railway club, one of the creators of the first Soviet rockets, engineer I. S. Merkulov, read a long lecture about the stages of the development of Soviet rocketry. A display was set up in the foyer of the club. A scientific conference was held at the Kaluga Pedagogical Institute imeni Tsiolkovskiy.

In September, several days before the 107th anniversary of Tsiolkovskiy's birthday, the museum, in cooperation with the regional committee of the VLKSM (Young Leninist Communist League of the Soviet Union) and the Regional Committee of the Voluntary Society for Assisting Army, Air Force and Navy (DOSAAF), held an autocross, devoted to the memory of Tsiolkovskiy, in which crews of sportsmen from several cities of the central regions of the country took part. The crosscountry race took place on an organized basis and attracted several thousand spectators.

Together with the regional administration on culture and the Kaluga branch of the RSFSR Union of Artists, the museum announced an open contest for the best souvenir dedicated to Tsiolkovskiy's memory.

The museum helped the regional childrens' technical station to organize a club of young astronauts. The first lectures about Tsiolkovskiy, about the development of the history of rocket technology and the achievements of astronautics, were read by the scientific co-workers at the museum.

On astronautics day in 1965, the museum presented lectures, conversations, displays, and a festival of films about astronautics. A city-wide gathering of young pioneers took place. In the city's universities, theoretical conferences were held.

At the invitation of the museum, astronauts F. Belyayev, A. Leonov, and P. Popovich arrived at Kaluga right after their space flight; representatives of the central press, radio and TV were also invited.

The guests became familiar with the memorial museum and the memorable sites associated with the name of Tsiolkovskiy, and examined the construction of the state museum; they also met with Kaluga workers at a triumphant meeting in the regional theater.

The traditional celebrations were held vividly and interestingly in connection with the 108th anniversary of Tsiolkovskiy's birthday. In the large hall of the House of Political Enlightment, an expanded session of the Learned Council was held. After a lecture dedicated to the memory of the great scientist, with recollections about him, people appeared who had personally known Konstantin Eduardovich. In one of the halls of the House of Political Enlightenment, a display was organized dedicated to the scientific-inventive activity of Tsiolkovskiy and the topic "Dirigibles in the Age of Space". In an issue of the newspaper *"Znaniye"*, dated 17 September, an entire page was dedicated to the jubilee date. /61

The printed word is one of the most important means for information and publicity. Many books, articles and outlines have been written about Tsiolkovskiy, but the participation of the museum in publishing activity began only in 1957, when in Kaluga the publishers of the regional newspaper *"Znaniye"* issued two brochures: the fantastic tale of K. E. Tsiolkovskiy "On the Moon" with a prologue concerning the author written by his grandson A. V. Kostin (printing run 26,000 copies), and the pamphlet by M. N. Denisov "The House-Museum of Konstantin Eduardovich Tsiolkovskiy" (printing run 2,000); the regional library published a short list of recommended literature under the heading " Konstantin Eduardovich Tsiolkovskiy, An Outstanding Russian Scientist-Inventor" (printing run 1,000). We should also mention the set, issued by *"Znaniye"* , of 10 postcards "100 Years from the Birthday of Konstantin Eduardovich Tsiolkovskiy" (printing run 25,000 items).

In later years, the museum has prepared and published an entire series of brochures, books and collections about Tsiolkovskiy.

Currently, we are preparing for press the " Collection of Memoirs Concerning K. E. Tsiolkovskiy". As a result of the many years' work, we have collected a vast and interesting compendium. The book will tell the reader about Tsiolkovskiy both as a man, scientist and thinker, patriot and social worker, as well as about the publicizing of science and pedagogy. The publication of the collection is being accomplished by "Priokskoye Book Press".

Many articles, outlines, and information leaflets have been published in the local newspapers. Radio broadcasting was used for the purpose of publicizing and information. Portions of the films "Road to the Stars", "Man from the Planet Earth" and "Great Foresight" were shot in Kaluga and at the Museum. Tsiolkovskiy has often appeared on the movie screens. In the museum, movies were made by the Moscow film study of scientific-popular films and the Leningrad and Moscow studios of movie chronology. The film groups of the Moscow central TV studio have also worked there, and an interesting documentary film about the museum was made in 1960 by the local childrens' movie studio *"Yunfil'm"*, organized under the regional station of young technicians.

On 19 August 1966, an army of millions of TV viewers saw and heard on national TV the first part of a series of broadcasts "Manuscripts of Famous Scientists". This part was dedicated to K. E. Tsiolkovskiy, to his manuscript and epistolary heritage, preserved in the Moscow Department of the Archives of the USSR Academy of Sciences and in the K. E. Tsiolkovskiy State Museum.

In 3 decades, the museum has accomplished extensive, diversified work in familiarizing the broad masses of workers with the life and scientific activity of our famous Kalugan, but immeasurably more work remains to be done. The museum staff will recall the words of Konstantin Eduardovich: "Always forward, without stopping. The Universe belongs to mankind".

COLLECTION OF THE SCIENTIFIC HERITAGE OF K. E. TSIOLKOVSKIY IN THE ARCHIVES OF THE USSR ACADEMY OF SCIENCES /63

S. A. Sokolova

At the present time, the entire scientific heritage of Tsiolkovskiy is mainly assembled in the archives of the USSR Academy of Sciences; its co-workers are working on the systematization and processing of the collection. Recently, a description of the Tsiolkovskiy materials preserved in the archives was published (Transactions of the Archives of the USSR Academy of Sciences, No. 22, Moscow, 1966).

The Tsiolkovskiy collection is quite extensive. In the Archives are around 400 manuscripts of Tsiolkovskiy's works, drawings, diagrams and tables to them, plus the blueprints and various jottings of the scientist.

The manuscript heritage of Tsiolkovskiy is of tremendous scientific and historical value. In the archives of the Academy of Sciences, are maintained the manuscripts of the scientist on various topics: aerodynamics and aviation, reaction devices and interplanetary flights, dirigibles, astronomy, biology, philosophy and various other problems in science and technology. Almost all of the pioneer works of Tsiolkovskiy on aviation, air navigation and interplanetary travel were published by the scientist himself. In later years, these materials were studied by a number of researchers, and by today all of the most valuable works of Tsiolkovskiy on aviation, air navigation and reaction flying devices have been published. However, even the remaining unpublished fragments of individual reports, rough drafts and working notes are of interest to researchers, since they allow one to analyze the process of Tsiolkovskiy's scientific genius, and in individual cases, to refine the dates of his discoveries, or to restore drawings or diagrams which seemed to be lost long ago.

At the same time, in other areas of knowledge, such as biology, astronomy and various questions of "Earth" technology, the works of Tsiolkovskiy were little known to anyone until recently, since most of them were in manuscript form. Certain of them were published for the first time in 1964, in /64
the fourth volume of the collected works of the scientist, in which of 29 reports, 13 were initial publications.

However, individual manuscripts exist which have not yet been published, including the first report of Tsiolkovskiy on biology "Mechanics of a Similarly Changing Organism" (1882), which received in its time a high evaluation by I. M. Sechenov. Tsiolkovskiy returned many times to biological problems. Among his still unpublished works, are included: "Effect of Varying Gravity on Life" (1920), "Biology and Man" (1932), and others.

However, of most interest at the present time are the reports by Tsiolkovskiy on the problem "Man and Space", which the scientist considered in great detail in his scientific creativity.

This problem interested Tsiolkovskiy throughout his entire scientific activity, starting from the report " Free Space" (1883), where for the first time he expressed the concept of applying the reaction principle for motion in outer space, up to his report "Maximum Velocity of a Rocket" (1935), in which he recommends a "Squadron" of rockets for the obtainment of high speeds. Both of these reports were published after his death.

Until recently, most of the students of Tsiolkovskiy's creativity have devoted attention to the study of the development of his technical ideas. Basically, they have been interested in the technical means of overcoming the Earth's gravity and the emergence of man into space. Starting in 1919, Tsiolkovskiy wrote many reports concerning the conquest of space by man, and the investigation of the conditions for life in outer space.

From among the reports on these topics, we should mention "Life in Outer Space" (written in 1919 - 1920, published in 1964 under the title "Life in the Interstellar Medium"). Here, he examined the questions of the working activity of man in outer space, the conditions required for life, and also the effect of weightlessness upon the human organism and the accomplishment of various tasks. In this report and in the unpublished manuscript "Extension of Man into Space" (1921), diagrams are provided for various types of human living accomodations under conditions of prolonged existence in space. From 1923 - 1924 in the working notes "Stages of Industry in the Ether", Tsiolkovskiy discusses his plan for the gradual conquest of interplanetary space. Simultaneously, Tsiolkovskiy was interested in the question of the existence of extraterrestrial life and the possiblity of man living on other planets. /65
Many of the reports from this series of his works are still unpublished. These include "Conditions of Life in the Universe" (1920, 1924), "Intelligence and the Stars" (1921), "Conditions of Life on Other Worlds" (1923, 1927), "Conditions of Biological Life in the Universe" (1927) and others. The basic content of these reports concerns the infiniteness of the universe and the possibility of the existence of life, including intelligent life, on other planets. As a result of a review of the structure of the universe and the conditions necessary for life, Tsiolkovskiy arrives at a conclusion to the effect that the most suited for the development of life are planets "with a size of tens of thousands of kilometers".

Many ideas expressed by Tsiolkovskiy in his reports, especially the systems for a settlement of man in the universe, the "Space Greenhouses", and many others even now seem fantastic and unrealizable. However, if we take individual drawings from his "Album of Space Voyages" (several of them were published in No. 22 of the Transactions of the USSR Academy of Sciences Archives), in which Tsiolkovskiy systematically depicts the time of the emergence of man into space, and the pattern of the accommodation of people in space suits in outer space near a rocket ship, they appear so modern to us that they permit us to admire again and again the intuition and the scientific foresight of the scientist, knowing that all of this had been developed by Tsiolkovskiy as early as 1933. Therefore, we are justified in assuming that evidently in the near future, even the "Space Greenhouses" of Tsiolkovskiy, and the multi-storied living quarters for the accomodation of man in interplanetary space, will be converted from the area of science fiction to reality.

Tsiolkovskiy's philosophical works have not been studied from the modern scientific standpoint either. About two years ago, the Committee on the development of the scientific heritage of Tsiolkovskiy referred this question to the Institute of Philosophy of the USSR Academy of Sciences, where at present, a group has been created which is proceeding to study the esthetic, psychological and sociological studies raised by the scientist. It is apparent that a collection of the selected works of Tsiolkovskiy on the questions, with detailed scientific commentaries to them, will be prepared and published.

The *epistolary* heritage of Tsiolkovskiy independently represents considerable scientific and cognitive interest. Konstantin Eduardovich carried on an active correspondence both with many scientific organizations and societies and with numerous private correspondents, i.e. with native and foreign /66
scientists, engineers, writers, students and many others.

The correspondence included a very broad range of questions and characterizes Tsiolkovskiy as a scientist, man, thinker, and citizen.

Unfortunately, the archives have access to a relatively small number of the personal letters of the scientist (the total number is slightly more than 400), sent for retention in the archives by several organizations and individuals. We are able to judge the extensive and diversified correspondence only on the basis of the letters sent from the correspondents and carefully kept by Tsiolkovskiy.

Tsiolkovskiy corresponded with scientific societies: with the Russian Physico-Chemical and Technical Societies, with the Socialist Academy of Humanities, with the Society for the Study of Interplanetary Travel, with the group for the study of Reaction Motion, the Reactive Scientific-Research Institute, with a number of social organizations (also *Osoaviakhim, ASSNAT*--the association of self-educated naturalists), with the publishers and editors of many newspapers and journals, etc. The materials pertaining to the correspondence on Tsiolkovskiy with establishments and organizations number around 200 works: here we find the writings of the scientist concerning the construction of his dirigible, tests on air resistance, rocketry, and numerous letters about the publication of his works.

Of no less interest, and perhaps more, is Tsiolkovskiy's correspondence with individuals. This correspondence provides us with the opportunity of understanding more fully the scientific ties of Tsiolkovskiy with domestic and foreign scientists, and to trace how his individual scientific ideas spread in our country and abroad.

Correspondence occupied a major part in the life of the scientist. Tsiolkovskiy replied quite promptly to his many correspondents. He attempted to publish the excerpts from certain letters, and also his brief replies, inserting them at the end of his reports published in Kaluga. However, these publications are a drop in the ocean as compared to the tremendous number of letters retained in the archives.

The number of Tsiolkovskiy's correspondents comprises more than 900 people. In Volume 5 of the edition of Tsiolkovskiy's collected works being prepared for publication, there will be included basically all of the letters written by the scientist at the disposal of the Committee. Here, will be published the Tsiolkovskiy letters to D. I. Mendeleyev, A. G. Stoletov and M. Ye. Zhukovskiy. Also to be included are the writings of the scientist to Professors V. P. Vetchinkin, N. A. Rynin, V. A. Semenov, engineers B. B. Kazhinsk, Ya. A. Rapoport, B. N. Vorob'yev, F. A. Tsander, G.E. Langemak, V. V. Rymin, A. B. Shershevskiy, mechanic-inventor Yu. V. Kondratyuk and others, including the writers Ya. I. Perleman, L. Kassil' and A. R. Belyayev. They will also publish the Tsiolkovskiy letters to the members of his family, /67
to his daughters Lyubov' Konstantinovna and Mariya Konstantinovna.

Most of the letters will be published for the first time and doubtless will be of great interest to the students of Tsiolkovskiy's creativity.

In the Archives of the USSR Academy of Sciences, there are assembled various versions of an autobiography of Tsiolkovskiy, many autobiographic and biographic documents and the notebooks kept by the scientist. The latter are also of high scientific interest. Along with the various notes of a daily and working nature (notes about his health, addresses, excerpts from the minutes of various meetings, etc.), the Tsiolkovskiy notebooks (memoirs) contain, as he notes himself, "Remarks and thoughts, in order not to forget to perform or to develop". Here we find brief notes on concepts about a new principle for a rocket (1920), discussions about electrons, cathode beams, radium, notes about his work on a dirigible, rough drafts of rocket engine diagrams using liquid oxygen (lox) and oil, excerpts from "press comments" on Tsiolkovskiy's work, notes about the activities of Oberth, Goddard, and many others.

The "Notebooks" of Tsiolkovskiy are of great interest both to the biographers of the scientist as well as in analyzing the development of his versatile scientific genius.

Finally, in the Archives many personal copies of Tsiokovskiy's published reports are shelved. It is known that during his life, most of the reports were published by the author himself. They were usually published in Kaluga, and appeared in short printing runs; at the present time, they are a bibliographic rarity. In many of the author's copies of the reports, in the margin and in the text, we find the working notes made by Tsiolkovskiy, which in a number of cases afford the opportunity of judging the development and the modification of his individual scientific views.

The archives also contain a small part of Tsiolkovskiy's scientific library. There are books with autographs. Thus, in the book by Yu. V. Kondratyuk "Conquest of Interplanetary Space" (1929), we find the inscription: "Presented with respect to the pioneer in the study of interplanetary travel, from the author. Yu. Kondratyuk". Among the books in the library is: "Roads into Outer Space", with the courtesy signature of its donor-author, G. Oberth.

The personal Tsiolkovskiy library is also interesting for a study of his creative work, i.e. it affords us the opportunity of establishing what literature he had available and which he used; in certain cases, it also permits us to judge his personal relationships with individual scientists. /68

The entire scientific creativeness of Tsiolkovskiy was subordinated to one purpose: "To do something useful for people...to advance mankind even a little forward". The entire versatile genius of the scientist was subjugated to solving this main problem "everything for man, everything for his welfare".

His concern about mankind, the creation of new possibilities for him, and in the final analysis the education of a new man, also establish in Tsiolkovskiy the necessity to develop science and technology in the most diversified fields, in order to encompass the problem "man and nature" from all sides.

Many of the scientific theories of Tsiolkovskiy have already been converted to reality: man has entered outer space; on Earth, we have developed high-speed devices moving on an air cushion; the studies of the oceanic depths in bathyscaphes have begun; studies are underway on the more effective utilization of solar energy, and bionics is being widely developed. However, many theories advanced by the scientist still wait to be realized. We can hope that we will witness the conversion of still many more scientific visions of K. E. Tsiolkovskiy to reality.

K. E. TSIOLKOVSKIY AND THE FIRST PRACTICAL STEPS IN SOVIET ROCKETRY /69

Yu. V. Biryukov

The deeper man penetrates into space, the more the fame of Tsiolkovskiy increases. This is explained by the fact that the remarkable scientist not only founded cosmonautics as a science and indicated a liquid-propelled rocket as the most realistic means for the achievement of space flights, but also provided a complete scientific pattern for the development of cosmonautics and indicated the necessity of making human society space-oriented. He was the first to enunciate scientifically the possibility of the infiniteness of mankind's existence, the infinity of his progress, and pointed to cosmonautics as the means for maintaining this infinity [1, p. 139]. No matter how far mankind has now advanced on the road into space, for the foreseeable future he will proceed along the path indicated by Tsiolkovskiy, and will follow the pattern outlined by him. This is the basic aspect which establishes the importance of Tsiolkovskiy's genius in the development of mankind. At the same time, the founder of astronautics also played a major role as a teacher in the period of the first steps of practical modern rocketry and above all, of Soviet rocket technology.

The actual pattern of the conquest of the universe, its vast significance for the future, and its limitless possibilities had to be grasped by those who have read the "Investigations of World Space by Reactive Devices". The statement that this matter is already within the power of mankind, that it should be started now, although it will be finished only in the remote future, caused special interest, and the desire to apply one's effort to this work...Tsiolkovskiy understood this well, and without underestimating the difficulties in any way, he attempted to justify as completely as possible the possibility of the development of space rockets.

While the French researcher R. Esnot-Peltry stated that space flights /70
would become possible only after the discovery of new energy sources such as radium and atomic power, in 1914 Tsiolkovskiy wrote: "The successful building of a reaction device in my view involves tremendous difficulties and will require many years of preliminary work, including theoretical and practical research, but nevertheless these difficulties are not so great as to be limited to dreams of radium and as yet nonexistent phenomena and bodies". Therefore, he constructed the plan of his rocket "according to possibilities, on a practical basis", not setting his hopes on the idea that "any discoveries are possible, and that dreams can suddenly be realized" [1, p. 143]. Warning that his work "by no means considers all aspects of the matter and certainly does not solve it from the practical respect in relation to realizability" [1, p.73], at the same time he attempted to examine the question as broadly as possible and to indicate the actual way for solving the most complex problems. It was specifically in order to indicate the reality of his rocket that

Tsiolkovskiy made a large number of calculations, of strength estimates, estimations of temperatures and pressures, evaluations of the effectiveness of various fuels, and indicated the design solutions of basic units and subassemblies. It is also necessary to point out that in most cases, all of his evaluations and comments are surprisingly valid; the order of magnitude of the values obtained by him almost always correspond to the actual value derived from the development of rocket technology and astronautics. Therefore, it is a fact that in the hands of the pioneers of rocketry, his reports have become raw data for the development of the first Soviet rocket. We are able to state that in 20 - 30 years in the USSR there is not one worker in rocketry who has not studied the works of Tsiolkovskiy and who has not used them in his work. In some form or other, all of them have written or spoken about this, justifiably calling themselves the students of Tsiolkovskiy. For example, this is what was written to Konstantin Eduardovich concerning his works on 19 May 1931 by one of the leading workers at the GDL[1] G. E. Langemak (to become later one of the creators of the famous "*Katyushi*): "These reports, in spite of their brevity, and perhaps because they contain nothing superfluous, constitute an inexhaustible store of the most valuable information not only from the standpoint of theory and of general scientific substantiation of reactive flight, but also in the area of the design development of all basic parts."

"In the nature of my work, I often am required to perform studies myself in this area and to examine foreign plans and proposals, and I always know in /71 advance that even that which at first glance appears new and original, has already been foreseen in some of your reports, sometimes expressed in several lines or even words, but always clearly and specifically, that no doubts remain concerning the priority" [2].

Tsiolkovskiy did not limit himself merely to demonstrating what a rocket should represent, how to solve any of the problems associated with it, but also taught how to proceed in an organized and methodical way to the development of rocketry; he demonstrated this in his letters to the Society for the Study of Interplanetary Travel (SSIT), to the GSRM, to the RSRI, in his reports: "Space Rocket. Experimental Preparation", "Stellar Navigators", "Theory of Jet Propulstion", and others, and also communicating directly with the future developers of rocket engines, rocket boosters and spaceships. Many outstanding Soviet scientists and designers got their start in rocketry here in Kaluga, in the modest little house above the Oka River and decided to devote their life to it.

Such was the activity of Tsiolkovskiy, directed toward indicating the reality of rocketry; it continued to have an influence involving talented youths in this work, extending all kinds of aid to those who took up the study of rocketry. Even during his life, the ideas of the great scientist began to be embodied in reality. We could cite many examples of the embodiment of Tsiolkovskiy's ideas even in the rocketry of the pre-war period.

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[1] GDL = Gas Dynamics Laboratory.

Of great importance for the entire development of rocketry was the discovery by Tsiolkovskiy of the basic law of a rocket's motion, expressed by his famous formula connecting the maximal velocity of a rocket with the ratio of its masses and the velocity of the exhaust stream. This discovery by Tsiolkovskiy indicated quite clearly and unequivocally the basic ways for the development of rockets: increased velocity of efflux and improvement in the mass ratio. Tsiolkovskiy himself was the first to use this discovery, having given the world his invention of a liquid-propelled rocket, which in principle should have much better characteristics than the solid-fuel rockets which had existed at that time. In reality, in the liquid-fuel rocket, one could utilize various liquid fuels having much greater effectiveness than powder, and the liquid-fuel rocket could be made with an appreciably lower relative structural weight, since the supply of fuel in it was located in special tanks at low pressures and temperatures, not in the combustion chamber.

The advantages of the liquid-fuel rockets were justified by Tsiolkovskiy /72
so profoundly and convincingly that Soviet rocketmen from the very first practical steps began to pay tremendous attention to them. The members of the SSIT intended to start work on liquid-fuel rockets. The first practical tests made by F. A. Tsander were also directed toward the development of liquid-propellant rockets. Also in the LGDL (Leningrad Gas Dynamics Laboratory), after work was started in the development of a solid-fuel rocket weapon, as soon as the question arose concerning the development of long-range rockets, intensive work immediately began on the development of engines and rockets based on liquid fuel. As concerns the GSRM, almost the entire activity was concentrated on liquid-propellant rocket technology. Subsequently in the RSRI, in spite of the fact that the work on liquid-fuel engines and rockets was much more complex than on solid-fuel (powder) rockets, and promised a much later practical outcome, considerable attention continued to be devoted to it; constantly, up to the war itself, no less than half the RSRI workers were engaged in this area.

In his works, Tsiolkovskiy laid the foundations for the science of rocket fuel; he indicated the numerous requirements for these fuels, and studied dozens of combinations of oxidizers and fuels for compliance with these requirements and indicated their most suitable combinations. Specifically, he indicated one of the most effective chemical fuels; liquid oxygen and liquid hydrogen, and the fuels most available and quite acceptable in effectiveness: lox + hydrocarbons (gasoline, kerosene, alcohol) and compounds of oxygen with nitrogen + hydrocarbon. These latter fuels also became the basic types of liquid rocket fuel used in the USSR in the pre-war period. Moreover, in the LGDL where basically studies were underway on the development of a rocket weapon, a high-boiling fuel convenient for operations was adopted as the basic fuel after the very first test: nitric acid and kerosene. In the GSRM, where the projects were directed primarily toward the accomplishment of manned rocket flight, first into the stratosphere, then into outer space, highly effective liquid oxygen was immediately adopted as an oxidizer; however, lox is very awkward to handle. Efforts were made to utilize benzene, kerosene and metals as fuels. However, the difficulties involved in the use of these fuels could not be overcome at that time; therefore, the GSRM workers were forced to use a somewhat weaker fuel, namely ethyl alcohol. In spite of this, the specific thrusts obtained in the GSRM and then in the RSRI from the alcohol-oxygen engines were the highest at that time in the entire world of rocket technology. Nevertheless, the Soviet rocketmen continued to conduct studies of new, more effective rocket fuels, and as early as 1936 in the USSR, a special monograph was published devoted to liquid rocket fuel. /73

Along with the liquid-propellant engine, Tsiolkovskiy devoted much attention to the problem of the development of air-breathing jet engines, indicating that the use of the oxygen in the air can greatly reduce the supplies of fuel required in a space rocket for entry into orbit [1, pp. 188 and 234]. F. A. Tsander devoted much attention to the development of air-breathing jet engines. Under the supervision of Yu. A. Pobedonostev, in the GSRM an entire staff worked on air-breathing jet engines; this group was the first to make a bench test of an air-breathing jet engine and also to make an actual flight test. This work was also continued in the RSRI. Before the war, under the supervision of I. A. Merkulov, the world's first missile equipped with a ramjet engine was created and successfully tested in flight, developing a thrust greater than its drag.

Among the many procedural instructions of Tsiolkovskiy which his students utilized, we also include his recommendations to start the work with relatively small rockets. Konstantin Eduardovich taught that the smaller the rocket, the easier it is to develop, but that when the small rockets have developed, when the necessary experiments have been conducted on them, enough experience will have been accumulated; then the transition to large rockets will no longer present any major difficulties. In reality, in the USSR during all experiments and economic considerations, only small rockets were developed, with launch weights ranging from tens to several hundreds of kilograms. At the same time, in the western press, reports were often seen of attempts being undertaken in the West to develop huge rockets; they even indicated the dates of forthcoming sensational flights with these rockets. However, when the promised time arrived, the newspapers were silent about the fact that the plans scheduled by them had proved unrealizable.

The experience acquired in the USSR with the aid of small rockets, and the scientific and engineering staffs trained in this work, permitted our rocket technology (when this was required and when a sufficient industrial-economic base had been created) to be the first in the world to proceed to the creation of the gigantic space boosters, which excited the imagination of the entire world.

Tsiolkovskiy spoke as follows about these ways for the development of rocket technology. "Two main routes are indicated so far for stellar navigation: 1) the gradual transition from the airplane to the spaceship and 2) a purely reactive (rocket) device" [1, p. 340]. From the very first steps, the Soviet rocketmen have proceeded simultaneously along both these lines. /74

The stages in the aviation approach were made up of the rocket aircraft RP 1, RP 318, BI and an entire series of winged automatic rockets. The purely rocket approach (having started with the 09 rocket) has already brought man into space through an entire series of designs for ballistic rockets. The movement into space along the aviation route so far has lagged somewhat, but currently, in proportion to the expansion of the space programs, the aviation approach is becoming more and more promising.

Speaking of the general approaches in the development of rocketry, it is noteworthy that owing to the clear instructions of Tsiolkovskiy concerning the suitability of rocket engines only at tremendous velocities, Soviet rocketmen succeeded in avoiding the expenditure of effort and time on rocket automobiles, sleds and gliders, a noisy, but practically useless stage, which the western researchers passed through.

Let us now dwell on several examples of the influence of Tsiolkovskiy's ideas on the design of the first rockets. In his reports, he devoted considerable attention to the problem of fuel delivery to the engine. Although he saw the basic solution of this problem as the application of a pulsing regime of engine operation, nevertheless he also pointed to other ways for its solution; specifically, he formulated the idea of fuel supply by the actual energy contained in the fuel, without any appreciable loss [1, p. 147]. From the very outset, attempts were made to solve this problem in the LGDL, the GSRM and the RSRI, where closed cycle turbopump delivery systems were developed with the recovery of gas from the combustion chamber to drive the turbines. Unfortunately, in those years, technology was not able to achieve this promising delivery system. Tsiolkovskiy also suggested an injection feed, investigated in detail by Tsander in connection with the fact that he proposed the utilization of powdered and molten metal as a fuel in his rocket engine.

As is known, rocket technology, as no other field, deals with a tremendous range of temperatures: namely, from several thousands of degrees in the combustion chamber of an engine to the cryogenic temperatures of the low-boiling fuel components. Konstantin Eduardovich was particularly interested in the problem of the breakdown of an engine from excessive heat, and he indicated ways of solving this problem: the application of refractory heat-insulating materials and external cooling of the combustion chamber and the nozzle, or a special coolant circulating in the jacket or with the fuel components, and also the simultaneous use both of heat-insulation and external cooling. All these approaches found broad application in the design of pre-war engines. In them, use was made of a graphite, ceramic and asbestos /75
internal heat insulation of the combustion chamber and of the nozzle, external cooling by lox, alcohol, nitric acid and also water. Quite extensive use was also made of a combination of internal heat insulation with external cooling. All this permitted us to proceed gradually to a reliable solution of the problem of providing the heat resistance of the chamber in the liquid-fuel engine. While the first engines could withstand operation only for several seconds, the engines of immediate pre-war models could operate for several minutes.

As concerns the use of cryogenic fuels, Tsiolkovskiy indicated the operating difficulties associated with them, but at the same time, he pointed to the surmountability of this problem by the appropriate heat insulation and the construction of tanks like Dewar vessels. In addition, he demonstrated that rockets with a brief time for the storage of lox could use conventional tanks successfully without any heat insulation, as was soon confirmed by the design and operation of the GSRM rockets 09, GSRM S, and 07.

Still another range of problems which found its reflection in the works of Tsiolkovskiy and which immediately demanded actual solutions in the very first practical steps of rocket technology included the problems of stability and controllability of rockets. Even in the very first reports, Tsiolkovskiy listed all the basic methods of controlling rocket flight, which were applied in the later development of rocket technology: air rudders, the shifting of masses within the device, gas-type rudders, the rolling of the nozzle as a control organ; gyroscopic, magnetic and astronavigational devices as instruments for an automatic control system [1, pp. 74, 75]. Since all of the rockets built in the pre-war period flew in the atmosphere, they used only air rudders with gyroscopic automatic stabilization devices.

We could say much more about the use by Soviet rocketmen of Tsiolkovskiy's advice concerning the importance of selecting the best planning parameters of rockets and optimal flight trajectories, concerning the application of a preliminary acceleration by rocket boosters, concerning the use of the principle of multi-stage rockets, the launching of a rocket from a high altitude balloon, and also concerning many other major and minor features of rocket technology. However, even from what has been stated above, it is obvious that the founders /76 of domestic rocketry, have used many of the ideas and suggestions of Tsiolkovskiy, overcoming the many difficulties which always arise among the long path of converting even the most progressive ideas into reality. But, nevertheless, that which has already been used is only a small part of that wealth which is contained in his works. In our days, when practical cosmonautics has begun to be developed successfully, while practical modern rocketry has already covered such a long, 40 years' path, we will see again and again that the developers of modern rocket-space hardware, already proceeding from the logic of the development of rocket and space technology, based on its richest experience, will arrive very often at those conclusions which were predicted with such insight by Tsiolkovskiy, when neither modern rocketry nor practical astronautics yet existed. Nowadays, we can repeat the valid words of Academician S. P. Korolev, uttered by him concerning Tsiolkovskiy at the celebration of the hundredth anniversary of his birthday: "At the present time, it is still impossible to evaluate fully the entire significance of his scientific ideas and technical proposals, especially with respect to penetration into outer space...

...His ideas on concepts will attract more and more attention in proportion to the further development of rocketry. Konstantin Eduadovich was a man who lived long before his time, just as a true and great scientist should live [3].

This is why the writings of the great Soviet scientist are not becoming obsolete and never will! This is why, with each year the respect of all progressive mankind for the scientific feat of Konstantin Eduardovich Tsiolkovskiy increases!

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DEVELOPMENT OF TSIOLKOVSKIY'S IDEAS ON THE USE OF AIR IN THE ENGINES OF SPACE VEHICLES /77

V. P. Kaznevskiy

Tsiolkovskiy, the founder of rocketry and astronautics, devoted considerable importance to the question of utilizing the gases in the Earth's atmosphere in reactive engine units. A number of his remarkable studies along these lines are well-known.

One of the examples of the further development of the use of atmospheric gases in space vehicles is the famous flight with the accumulation of air. The mechanics of flight with the accumulation of mass is as follows:

An aircraft in orbital flight moves in the upper layers of the planet's atmosphere. During movement in a circular unperturbed orbit, the following forces act upon the vehicle:

$$R = Q \text{ and } G = I$$

where the thrust R compensates the drag force Q, while the weight of the device, G, is compensated by the centrifugal force, I.

The thrust force of such a device does not depend on its weight.

With certain assumptions for the accumulating device, the following equations are valid:

$$Q = m_v V_{orb}$$
$$R = m_c W,$$

where m_v = the mass of air arriving at the air collector per second; m_c = the air mass consumed per second in the engine unit; V_{orb} = the orbital velocity of the device; and W = the velocity of the air stream from the engine unit.

From the equations given, it follows that /78

$$\frac{m_v}{m_c} = \frac{W}{V_{orb}}.$$

If we retain the condition that the velocity of the incident air entering the air intake of the device V_{orb}, is less than the exhaust velocity of this air from the engine - W, air will then accumulate onboard the device, i.e. the flight will be accomplished with an accumulation of mass.

In electrical rocket engine units, we can obtain a gas exhaust velocity greatly exceeding the orbital velocity, i.e. by 3 - 10 and more times. Such engine units are being considered for application in orbiting accumulator devices. These units consist of a nuclear reactor, an energy converter, an impeller and a very sophisticated cooling-radiating device for the removal of the unused part of heat into space.

The air (m_v), entering the intake is subjected to stepwise cooling and compression. Thereupon, a part of the air (m_c) enters the engine unit, while another part ($m_v - m_c$), accumulates in the tanks. The cooling of the air and its compression requires that the accumulator device carry a cooling unit, operating in a closed cycle, with the removal of the heat into outer space using the well-designed surfaces of the cooling radiators.

The energy source required for prolonged operation of the compression system is a nuclear reactor, supporting the operation of the electrical rocket propelling agent (propulsion motor).

Thus, for a vehicle with the accumulation of air, it is required that:

1. The engine unit use air or its components as an actuating medium;

2. The engine unit intended for overcoming the aerodynamic drag satisfy the condition

$$W > V_{orb} .$$

3. On board the vehicle, there must be a system for the capture of air, and a cryogenic system for its compression.

Orbital accumulating devices characteristically can exist in orbit actively for a long time, can accomplish maneuvering and achieve the accumulation of mass, not depending on Earth for supplementing their power and fuel (air). /79

The flight of vehicles with the accumulation of air can be accomplished at altitudes of about 100 - 160 km. The orbit can be either circular or elliptical.

In distinction from a circular orbit, during an elliptical orbit the accumulation of air is accomplished only in the lower part of the orbit, and the accumulation time is naturally lengthened.

The equation determining the current mass of the accumulating device in the stage of accumulation, and then in the maneuvering stage, i.e. flight with the consumption of the accumulated mass, has the following form:

$$M = M_u + M_e + \int_0^{t_1 \leq T} (m_v - m_c)\,dt_1 + a\int_0^{t_1 = T} (m_v - m_c)\,dt_1 - m_c t_2 .$$

At m_v and m_c = const, this equation acquires the form:

$$M = M_u + M_e + (m_v - m_c)(t_1 + aT)\, m_c t_2 , \qquad (1)$$

where t_1 = the flight time under conditions of accumulation of mass; t_2 = the time operated by the engine up to the present moment in the active flight regime ($t_2 \leq T_2$); T_2 = the full time of expenditure of mass during active flight), T = the time of complete buildup of fuel; M_u = the useful mass; M_e = the mass of the engine and storage unit; a = the relative mass of the fuel tanks.

The flight regime with the accumulation of the working substance occurs at $t_2 = 0$ and $t_1 \neq 0$. The flight regime with the expenditure of the working substance occurs at $t_2 \neq 0$, and $t_1 = T$.

It is evident that equation (1) at $t_1 = 0$ determines the mass of the device at the beginning of accumulation, while at $t_2 = 0$ and $t_1 = T$, it determines the mass of the device at the end of accumulation.

From the condition of the conservation of thrust, in the stage of accumulation and stage of maneuvering, R = const, the following relationship is valid:

$$\frac{T_2}{T} = \frac{m_v - m_c}{m_c} ,$$

from which, at $t_1 = T$, the maneuvering time of the device to full consumption of accumulated mass will be:

$$T_z = T\left(\frac{m_v - m_c}{m_c}\right).$$

On the basis of Eq. (1), the current value of the Tsiolkovskiy number, depending on the current time, t_1 or t_2, is established by the equation: /80

$$Z = 1 + \frac{t_1(m_v - m_c) - m_c t_2}{aT(m_v - m_c) + M_u + M_e}. \qquad (2)$$

This equation is valid both for the sector of mass accumulation and for the sector of mass consumption (expenditure).

Equation (2) for the Tsiolkovskiy number permits us to obtain the time for doubling, tripling, etc. of the initial mass of the accumulating device. Having assumed in this equation that $t_1 = T$ and $t_2 = 0$, we obtain the above-specified time:

$$T_Z = \frac{M_u + M_e}{(m_v - m_c)\left(\frac{1}{Z-1} - a\right)},$$

where Z can acquire the values 2-3-4, etc., but not more than the critical value determined by the equation

$$Z = \frac{1+a}{a}.$$

The equation for the critical value of Z is obtained from Eq. (2) at $t_1 = T$, $t_2 = 0$ and under the assumption that $T \to \infty$.

In the case of utilizing the accumulating device as a refueling station we can establish the minimal economic value of the Tsiolkovskiy number Z_e, at which the cost("h") of obtaining the liquid working substance e.g. oxygen in orbit, becomes equal to the cost ("b") of its preparation on Earth and delivery into orbit.

The above-cited condition is fulfilled at

$$\psi = \frac{b}{h} = \frac{b}{\frac{f M_1(T)}{K M_T(T) d}} = 1,$$

$$M_1(T) = M_u + M_e + aT(m_v - m_c), \qquad (3)$$

where M_1 (T) = the mass of the empty storage device depending on the time of the complete accumulation of fuel; K = the number of discharges of the accumulated working substance; T_Σ = the total time of accumulation, depending on the capacity of the accumulating device; f = the cost of a unit of mass of the empty storage device; d = the relative content of oxygen in the air; and /81
$M_t(T)$ = the mass of working substance accumulated during complete accumulation time, $M_T = T(M_v - M_c)$.

The ratio

$$\frac{M_1(T)}{M_T(T)} = \frac{1}{z(T) - 1}$$

then Eq. (3) can be written in the form:

$$\psi = \frac{b d K T(m_v - m_c)}{f M_1(T)} = \frac{K b [z(T) - 1]}{f} = 1. \qquad (4)$$

From Eq. (4), we obtain the minimal economic value of the Tsiolkovskiy number

$$z_e = 1 + \frac{f}{K b}.$$

From Eq. (4), we can also derive the minimal economic existence time T_e of the storage device, at which the cost of obtaining the liquid working substance in orbit becomes equal to the cost of its production on Earth and delivery into orbit. This time equals:

$$T_e = \frac{f M_1}{(m_v - m_c)(\delta d k - f a)}.$$

At $\psi = 1$, $T_e = T_\Sigma = kT$.

It is obvious that at $\psi > 1$, $T_\Sigma > T_e$

Knowing the dependence of the Tsiolkovskiy number on t_1 and t_2, and using his basic formula for the maneuvering of the storage device, we can determine:

1) what increment in velocity (V) the storage device can accumulate by complete expenditure of the accumulated mass. This increment of velocity is determined by the equation:

$$V = W \ln\left[1 + \frac{t_1(m_v - m_c)}{aT(m_v - m_c) + M_u + M_e}\right].$$

2) what reserve of velocity increment (V_1), after each section of active flight, the vehicle still has with partial consumption of fuel. This reserve in the velocity increment is determined by the equation: /82

$$V_1 = W \ln\left[1 + \frac{t_1(m_v - m_c) - m_c t_2}{aT(m_v - m_c) + M_u + M_e}\right].$$

During the maneuvering of the storage device equipped with a liquid-fuel rocket engine, operating on the stored oxidizer and fuel brought from Earth, the equation determining the velocity increment of the storage device to complete consumption of the accumulated oxidizer and fuel has the following form:

$$V = W_1 \ln\left[1 + \frac{T(m_v - m_c)(1 + \frac{1}{\nu})}{aT(m_v - m_c)(1 + \frac{1}{\nu}) + M_u + M_e + M_g}\right],$$

while the equation determining the remaining reserve of velocity increment with incomplete consumption of stored mass, at the end of each active flight sector, is as follows:

$$V_1 = W_1 \ln\left[1 + \frac{\left(t_1 + \frac{T}{\nu}\right)(m_r - m_c) - m_2 t_2}{aT(m_r - m_c)\left(1 + \frac{1}{\nu}\right) + M_u + M_e + M_g}\right],$$

where V = the ratio of the fuel components in the LPRE (liquid-propellant rocket engine); Mg = the mass of the LPRE; m_2 = the mass of fuel expended per second of operation of the LPRE; and W_1 = the gas exhaust velocity of the LPRE.

The complete period $T_2 = t_{2\,max}$, of operation by the LPRE during the full storage time, will be established from the condition:

$$T(m_r - m_c)\left(1 + \frac{1}{\nu}\right) - m_2 T_2 = 0.$$

From this

$$T_2 = \frac{T(m_r - m_c)\left(1 + \frac{1}{\nu}\right)}{m_2},$$

or

$$T_2 = \frac{T(m_r - m_c)\left(1 + \frac{1}{\nu}\right) I_{yg}}{P},$$

where P = the thrust of the LPRE, and I_{yg} = the specific pulse of the LPRE.

We have examined certain questions of flight with the accumulation and consumption of fuel in circumterrestrial space.

A spacecraft can begin a flight to another planet with accumulated working substance, calculated for a one-way flight. Having reached the target /83 planet, the vehicle can replenish its supply of working substance and use it for the return trip.

The use of a storage procedure under such a flight system can increase the relative payload of the device even more. In this context, the relative payload increases with an increase in the number of flight cycles.

We thus observe that the ideas of our remarkable scientist, K. E. Tsiolkovskiy, on the use of the gases in the Earth's atmosphere and that of other planets in the engine units of spacecraft, is being developed fruitfully in our times.

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DEVELOPMENT OF THE TSIOLKOVSKIY EQUATION IN THE WORKS OF NATIVE (SOVIET) SCIENTISTS

/84

A. G. Radynov

At the present time, when mankind has advanced to the direct conquest of outer space, more and more people are expressing interest in the theory of jet propulsion, and above all, in the works of K. E. Tsiolkovskiy. Interest is also growing in the reports by Soviet scientists who have continued and developed the basics of space science laid by Tsiolkovskiy. In the extensive creative heritage of the scientist, one of the outstanding places is occupied by the equations describing the motion of reactive devices which link the increment in the velocity of the rocket with the velocity of the exhaust gas (relative to the rocket) and the consumption of fuel. These equations derived by the scientist in the report "Investigation of World Space by Reactive Devices" [1] make possible the study of the motion of a rocket from a qualitative standpoint.

As is known, the principles of the mechanics of bodies of variable mass were developed by Prof. I. V. Meshcherskiy [2]. In 1897, he developed the basic equation for the motion of a material point of variable mass, which has the form:

$$M \frac{dV}{dt} = F - W \frac{dM}{dt}.$$

This equation has considerable basic significance in the history of the development of theoretical mechanics and especially in rocket dynamics. From the Meshcherskiy equation, as a specific case, under the assumption of constancy of mass, the second Newton Law develops, which is valid only for material points having constant mass.

At about the same time, Tsiolkovskiy, conducting a mathematical study of the movement of rockets, was developing a basic theory of reactive propulsion, having demonstrated that reactive devices are capable of accomplishing flight at cosmic speeds, and that in the absence of gravitational forces, the final velocity of a rocket depends only on the quantity of fuel stored in it and on the exhaust velocity of the combustion product from the rocket nozzle. The mathematical expression of this dependence is the Tsiolkovskiy formula, valid for the flight of a rocket in free space, i.e. outside of the atmosphere and far from large gravitating masses. This equation is derived from the law of conservation of the quantity of motion (momentum) of a closed system, which can be written as follows:

$$M\,dV + W\,dM = 0 \cdot$$ /85

The integral of this equation is the expression

$$V = W \ln \frac{M_0}{M} \qquad (1)$$

where M_0 = the mass of the rocket at the beginning of flight. This equation can also be written as:

$$\frac{M_0}{M} = e^{V/W} \ . \qquad (1')$$

The ratio of the mass of fuel M_t to the final mass M_k of the rocket, i.e. to the rocket mass after the consumption of the entire fuel supply, later was called the "Tsiolkovskiy number".

Tsiolkovskiy also studied a rocket's motion in a gravitationl field. He considered the case of a rocket's vertical flight beyond the atmosphere, in a constant gravitational field ($g = g_0$) at constant acceleration, j:

$$j = -\frac{W}{M}\frac{dM}{dt} = \text{const}.$$

The differential equation of motion in a general case of a variable gravitational field has the form:

$$M\,dV + W\,dM = -Mg\,dt.$$

From this, after integration, under the condition $g = g_0$, the Tsiolkovskiy equation has the form:

$$V = W\left(1 + \frac{g_0}{j}\right) \ln \frac{M_0}{M} \qquad (2)$$

or

$$\frac{M_0}{M} = e^{\frac{V}{W(1-g_0/j)}}. \qquad (2')$$

As was to be expected, in the gravitational field, the velocity increment at the same Tsiolkovskiy number is less than in free space, and at $j = g_0$, it even equals 0. In this case, the rocket will hang motionless in air, or will move with a constant speed until it exhausts the fuel. One should also remark that with instantaneous gain in velocity (i.e., at $j \to \infty$), this equation converts to the Tsiolkovskiy formula (Eq. 1). /86

It has been necessary for the Soviet scientists to wage a considerable effort in defense of Tsiolkovskiy's works. Although the foreign researchers began to develop the theory of jet propulsion 10 - 20 years later, in their reports they did not mention the efforts of Tsiolkovskiy. Later on, progressive foreign scientists recognized his talent. For instance, in Sept. 1929, G. Oberth wrote to Tsiolkovskiy: "...I send you my best greetings..I hope that you will attain the fulfillment of your high goals..you have lit the lamp and we will work until the greatest dream of mankind has been fulfilled" [3].

However, among the foreign scientists there also were those who attempted to downgrade Tsiolkovskiy's work. For instance, Prof. K. Betz discovered in 1930 in the press a discussion of the alleged lack of substantiation for the equation of a rocket's motion developed by Tsiolkovskiy [12]. Our scientists have not overlooked these attacks on the remarkable works of the founder of the theory of interplanetary travel and have proved the correctness of his theoretical works.

This task was brilliantly accomplished by M. K. Tikhonravov who proved the complete scientific validity of the Tsiolkovskiy theory and the insolvency of the attacks made on it [4].

Also of considerable interest is the study of the nature of rocket flight at constant thrust:

$$P = -W\frac{dM}{dt} = \text{const}$$

the formula for the motion of a rocket with constant thrust for the case of a constant gravitational field was first derived by A. A. Shternfel'd in 1937 [5]. Assume that the thrust force $P = kM_0g_0$ where k is a dimensionless coefficient, equalling the ratio of the thrust to the initial weight of the rocket.

Then, the differential equation of the movement acquired the form:

$$M\frac{dV}{dt} = kM_0 g_0 - Mg_0 .$$

From the condition of the constancy of thrust, the following dependence of the current mass upon the flight time ensues: /87

$$M = M_0\left(1 - \frac{kg_0}{W}t\right)$$

After integration, we derive:

$$V = W\left[\ln\frac{M_0}{M} + \frac{1}{k}\left(\frac{M}{M_0} - 1\right)\right]. \tag{3}$$

Let us consider still another case of rocket flight in a gravitational field, i.e. at constant velocity. Assume that the rocket, starting at a certain altitude H_0 (the distance from the center of the planet R_0), begins movement at the constant velocity V_0. In this connection, the thrust should compensate the force of gravity, i.e. now $j = g_0$. For comparison with the previous formulas, let us first investigate the motion in a constant gravitational field ($g = g_0$), then the acceleration of the rocket j will be constant

$$j = -\frac{W}{M}\frac{dM}{dt} = g_0.$$

Since $\frac{dR}{dt} = V_0 =$ const, we have

$$-\frac{W}{M}\frac{dM}{dR} = \frac{g_0}{V_0} .$$

From this, after integration we obtain:

$$R - R_0 = \frac{W V_0}{g_0} \ln \frac{M_0}{M} \tag{4}$$

or

$$\frac{M_0}{M} = e^{\frac{g_0}{W V_0}(R - R_0)}. \tag{4'}$$

All of the equations presented above are valid in the case when external forces are not acting upon the rocket. However, in reactive devices ejecting a gaseous substance (and the rocket is one of these), we should take into account the phenomenon of molecular interaction, resulting in the development of an external force. This force depends on the difference between the static pressure of the gas within the rocket, and in the external medium:

$$P_s = S_c (P_c - P_0),$$

where S_c = the area of the output section of the nozzle, P_c and P_0 = the static pressure of gases in the outlet section of the nozzle and of the ambient medium respectively. This additional force in the calculation of the thrust of rocket engines was already considered in the development of the first domestic (Soviet) rocket engine of the ORM series by the specialists at the Leningrad Gas Dynamics Laboratory. It was also taken into account by the specialists at GSRM in the design of their engines. /88

Outside of the atmosphere (i.e. at $P_0 = 0$) the force $P_s = 0$ only under the condition that in the outlet section of the nozzle, the gas pressure is infinitely low, and this can occur only with infinite dimensions of the nozzle. The Tsiolkovskiy equation taking the finite dimensions of a nozzle into account was derived in 1938 by I. A. Merkulov [6]. He considered the case of a flight of a rocket in an airless medium, outside of the force of gravitation, at constant fuel consumption $m = \frac{dM}{dt}$ = const. The equation obtained by him had the form:

$$V = \left(W + \frac{P_s}{m}\right) \ln \frac{M_0}{M} \tag{5}$$

and

$$\frac{M_o}{M} = e^{\frac{V}{W + P_s/m}}. \tag{5'}$$

We can derive an equation for the movement of a rocket with a nozzle of finite dimensions and in the presence of a gravitational field ($g \neq 0$). For the case of a rocket flight with a constant thrust force, the equation of motion has the form:

$$M\frac{dV}{dt} = P - P_s - Mg.$$

Assuming that the gravitational field is constant ($g = g_o$) after integration we get:

$$V = W\left[\left(1 + \frac{P_s}{mW}\right)\ln\frac{M_o}{M} + \frac{1}{k}\left(\frac{M}{M_o} - 1\right)\right]. \tag{6}$$

A considerable contribution to the development of the study of the motion of rockets was made by one of the founders of the theory of space flight, Yu. V. Kondratyuk [7]. He diverted attention to the fact that the so-called useful mass of a rocket $M_k = M_o - M_T$ consists of two parts: the actually useful load (payload), M_a, i.e. of people, objects necessary for their existence, devices, etc. and the mass of the rocket's structure M_δ. The first part of the mass was called by Kondratyuk "absolutely passive". Since the purpose of the flight is the delivery of some point of the mass M_a, it is preassigned, and unchanged during the time of flight. The second mass M_δ is said to be "proportionally passive" since it is roughly proportional to the mass of fuel and can be changed during flight, since the mass of fuel decreases continuously. Kondratyuk suggested the division of the flight of a rocket into n sectors, in which a uniform increment in velocity occurs, and over the extent of each of which there functions a fixed part of the mass M_δ, which is discarded at the end of the sector. He derived an expression indicating that during movement by this method, the mass required for the attainment of a specific velocity will be less than in the usual case. /89

The Tsiolkovskiy formula for a multi-stage rocket can be represented in the form:

$$\frac{M_0}{M} = \left(\frac{n}{n-1}\right)^{[(1+\varepsilon)n-\varepsilon]\frac{V}{W}} \qquad (7)$$

where

$$\varepsilon = \frac{M_\delta}{M_T}.$$

The Kondratyuk formula was generalized by Prof. V. P. Vetchinkin [7] for the case of the continual ejection of the "proportionally passive" mass, i.e. at $n \to \infty$. The equation developed by him has the following form:

$$V = \frac{W}{1+\varepsilon} \ln \frac{M_0}{M} \qquad (8)$$

or

$$\frac{M_0}{M} = e^{(1+\varepsilon)\frac{V}{W}}. \qquad (8')$$

These equations are valid for movement in free space. In the presence of a gravitational field in the case of movement at constant acceleration (at $g = g_0$), the following equations can be derived:

$$V = \frac{1 - g_0/j}{1+\varepsilon} \ln \frac{M_0}{M} \qquad (9)$$

and /90

$$\frac{M_0}{M} = e^{\frac{(1+\varepsilon)V}{(1-g_0/j)W}} \qquad (9')$$

If we take into account the finite dimensions of the nozzle, the Tsiolkovskiy formula for multi-stage rockets will have the form:

$$V = \left(W + \frac{P_s}{m}\right) \frac{1}{1+\varepsilon} \ln \frac{M_0}{M} \qquad (10)$$

or

$$\frac{M_0}{M} = e^{\frac{(1+\varepsilon)V}{W + \frac{P_s}{m}}}. \qquad (10')$$

Let us present several other cases of the analysis of the motion of rockets, conducted in the All-Union Committee of Astronautics of the All-Union Volunteer Society for Cooperation with the Army, Air Force and Navy, for which the Tsiolkovskiy formulas were developed.

For the case of rocket flight at constant speed, I. A. Merkulov derived in final form the Tsiolkovskiy formula during motion in a variable gravitational field, when

$$g = g_0 R_0^2 / R^2 .$$

If we take into account this dependence of the force of gravity upon the height of ascent, the differential equation of a rocket's motion will acquire the form:

$$-\frac{VW}{M}\frac{dM}{dR} = g_0 \frac{R_0^2}{R^2}$$

from this, after integration, the following equation will be obtained

$$\frac{R}{R_0} = \frac{1}{1 - \frac{V_0 W}{g_0 R_0} \ln M_0/M} \qquad (11)$$

or

$$\frac{M_0}{M} = e^{\frac{g_0 R_0}{V_0 W}\left(1 - \frac{R_0}{R}\right)}. \tag{11'}$$

Further, Merkulov considered the following case: A rocket in the course of a negligibly short time is accelerated to velocity V_1, covering during the acceleration period a negligibly short path; then with the engine operating, moves at constant velocity to height H_1 (distance from the center of planet R_1); at this height, at velocity $V_1 = V_0$, the engines are cut out and the rocket moves to height H. Under the effect of gravitational force, its velocity decreases to V. The case is considered of the flight (ascent) from planets with no atmosphere, i.e. air resistance is disregarded. The values V_1, V and H are considered fixed. The fuel consumption, at almost instantaneous acceleration of the rocket to the velocity V_1, is determined according to the first Tsiolkovskiy formula: /91

$$\frac{M_0}{M_1} = e^{V_1/W}.$$

The fuel consumption during flight at constant velocity according to formula (11')

$$\frac{M_1}{M} = e^{\frac{g_0 R_0}{V_1 W}\left(1 - \frac{R_0}{R}\right)}.$$

The height H_1, to which the rocket should rise with the engine operating, is determined from the law of the conservation of energy.

$$\frac{MV_1^2}{2} + \frac{Mg_0R_0^2}{R_1} = \frac{MV^2}{2} + \frac{Mg_0R_0^2}{R}.$$

On the left in this equation, we show the sum of the kinetic and potential energies at height H_1, and on the right, at height H.

From this equation, we derive the relationship

$$\frac{1}{R_1} = \frac{V_1^2 - V^2}{2 g_0 R_0^2} + \frac{1}{R}$$

after substituting which in the previous formulas, we finally get:

$$\frac{M_0}{M} = e^{\frac{V_1^2 + V^2 + V_{no}^2 (1 - R_0/R)}{2 V_1 W}}. \tag{12}$$

Here, $V_{no} = \sqrt{2 g_0 R_0}$ = the velocity required for overcoming the force of attraction of a planet, said to be the parabolic velocity or the second cosmic speed (as is known, for Earth, it is 11,189 m/sec). The expression obtained is the Tsiolkovskiy formula for flight at constant velocity in a gravitational field. It connects the consumption of the mass with the prescribed flight altitude $H = R - R_0$ and the velocity V of the rocket at this altitude at constant selected velocity of rocket flight with operating engine. /92
If the planets have an atmosphere, the formula can be used under the assumption that the velocity V_1 is imparted to the rocket in the extra-atmospheric region. However, in this case, the values R_0 and g_0 should be taken for the point of the beginning of flight at constant velocity.

For the flight of a rocket beyond the limits of Earth's gravitation ($R \to \infty$), from Eq. (12), we obtain the following equation:

$$\frac{M_0}{M} = e^{\frac{V_1^2 + V^2 + V_{no}^2}{2 V_1 W}}. \tag{12'}$$

If, in this connection, the rocket must not have any specific velocity relative to the planet, i.e. if V = 0,

$$\frac{M_0}{M} = e^{\frac{V_1^2 + V_{no}^2}{2 V_1 W}}. \tag{12''}$$

It is easy to observe that in this case the minimal consumption of mass will be at $V_1 = V_{ao}$. From this follows the known precept, that for flight into space, it is desirable to accelerate the rocket immediately to the required velocity, and then continue the ascent with empty tanks, without expending energy for raising the fuel.

In spite of the fact that in practice the rocket cannot be instantaneously accelerated to the required velocity over a small sector, the formula has practical interest, because in any case the acceleration sector is appreciably less than the radius of the planet's attraction.

V. P. Kaznevskiy considered still another interesting problem. In all of the cases analyzed before him, it was assumed that the rocket has fixed data, i.e. that the initial mass of the rocket and the mass of the fuel stored on board are assigned. Based on these two values and the velocity of the exhaust gas, the question is posed of establishing the velocity which a rocket can acquire. Kaznevskiy considered a rocket with variable parameters. This can occur, e.g. in the following case: a rocket is launched from the orbit of a satellite, and, having received the required increment in velocity, enters an interplanetary course. For the achievement of this maneuver, it is required that the engine be turned on for a specific time. In the process of further flight, the cosmonauts would also turn on the engine several times. The amount of fuel spent in all these maneuvers is determined by the total operating time of the engine in respect to the known value of consumption per second. In this manner, the reserves of fuel remaining in the rocket tanks /93
are a function of the active flight time. The author has expanded the problem and has included the conditions of accumulation, i.e. flights into the upper atmosphere, in the course of which the rocket accumulates the working substance, namely air or oxygen. The quantity of the accumulated mass is also determined by the flight time under conditions of accumulation.

For this problem, Kaznevskiy derived the Tsiolkovskiy formula in the following form:

$$V = W \ln\left[1 + \frac{(t_1 + T)(m_v \quad) + m_x t_2}{\varepsilon T(m_v - m_c)(1 + 1/\nu) + M_i + M_e}\right]$$

where t_1 = the current time of flight under the regime of accumulation of mass; t_2 = the time operated by the engine up to the considered moment under conditions of active flight; T = the time of complete accumulation of fuel in the tanks; m_v = the mass of fuel entering the air intake per second; m_c = the mass of fuel expended per second in the engine operating under conditions of the accumulation or expenditure of mass; M_e = the mass of propulsive and accumulating units; $(m_v - m_c)$ = the mass of fuel accumulated per second; V = the relationship of the fuel components of the chemical engine; m_x = the mass of fuel expended per second by the chemical engines.

The formula developed is convenient in that it permits us to determine what reserve of velocity will remain in the rocket at the end of each active flight sector, based on the known times of operation of the engine and of the storage unit without calculating the fuel supplies at each moment of rocket flight.

In the derivation of all the above-indicated Tsiolkovskiy formulas, it was assumed that the velocity which is being attained by a rocket, although it is high as compared with the standard Earth velocities, nevertheless is considerably less than the speed of light. However, even at the beginning of the development of astronautics, it became clear that for flight to remote worlds, we require velocities close to that of light. The problem arose of the extension of the Tsiolkovskiy formula to the case of high velocity, when the laws of the special theory of relativity come into force. The relationship characterizing the flight of a rocket and near-light velocities was studied by R. Esnot-Peltrie [8], E. Sänger [9] and others. Soviet scientists also paid much attention to this question. One of the sections of the book /94
(Introduction to Astronautics) was devoted to the motion of rockets with near-light velocities, written by A. A. Shternfel'd [5]. This problem was reviewed in detail by T. P. Stanyukovich [10]. For the derivation of this formula, use is made of the following equation from relativistic dynamics:

$$M\frac{dV}{dt} = F - \frac{FV}{c^2}V$$

where F = the three-dimensional force, equalling in our case the thrust:

$$P = W\frac{dM}{dt};$$ c = the speed of light.

Since the motion occurs along a straight line, we have

$$MdV = W\left(1 - \frac{V^2}{c^2}\right)dM$$

from this, we obtain the formula

$$\frac{M_0}{M} = \left(\frac{1 + \frac{V}{c}}{1 - \frac{V}{c}}\right)^{\frac{c}{2W}}. \tag{14}$$

It is easy to demonstrate that the velocity V will be close to the speed of light, if the exhaust speed W is also near the speed of light. For this, we assume $V_c = 1 - \Delta$, where Δ is small as compared with unity.

Then the equation has the form:

$$\frac{M_o}{M} = \left(\frac{2}{\Delta}\right)^{\frac{c}{2w}}$$

assume $\Delta = 1:5$, i.e. $V = 0.8C = 240{,}000$ km/sec; then

$$M_o/M = 10^{c/2w}.$$

If we set $W = C:20$, then $M_o/M = 10^{10}$, which is unrealizable; at $W = C:2$, $M_o/M = 10$, which can be achieved; however, if $W = C$, then $M_o/M = \sqrt{10} \approx 3$.

If we wish to attain a higher velocity, let us say $V = 288{,}000$ km/sec, the ratio of the masses at $W = C$ should equal 5. In practice, it is obvious that the maximal velocity of a photon rocket will not exceed 90 - 95% of the speed of light.

In all of the cases considered, it was assumed that the gravitational /95 interaction of a rocket with the fuel being discarded can be disregarded. In reality, in view of the relatively small masses of the spacecraft, the value of this interaction is trivially small. However, it is possible for the time to arrive when the hand of man will be able to "shift" in space, not only the spaceships, but also relatively large celestial bodies. For these, the so-called "attracting masses", I. A. Merkulov derived the Tsiolkovskiy formula:

$$\frac{M_o}{M} = e^{\frac{v}{w\sqrt{1-(V_{ao}/w)^2}}} \qquad (15)$$

where V_{ao} = the parabolic velocity on the surface of a gravitating mass being accelerated with the aid of a rocket engine.

It is worth noting that, along with the Soviet researchers, a great contribution to this area of space science has also been made by the foreign specialists, among whom we should mention Robert Esnot-Peltrie, Robert Goddard, Herman Oberth and Walter Hohmann.

Evaluating the outstanding contribution of Tsiolkovskiy to the theory of the motion of rockets, Prof. A. A. Kosmodem'yanskiy wrote in the introductory article to the second volume of the academy edition of Tsiolkovskiy's works:

"In the writings of Konstantin Eduardovich, we see the original innovator, the creator of new paths of research, a brave and original developer of a progressive trend in science...

It is specifically Tsiolkovskiy who has given to rocket dynamics that broad revolutionary scope and depth of inferences which are typical for the immortal creations of human intellect. This is the indisputable contribution of Russian science in the treasure of human culture" [11].

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THE PROBLEM OF HOMEOSTASIS IN SPACE MEDICINE /97

I. M. Hazen

Even in his early studies on astronautics, Konstantin Eduardovich Tsiolkovskiy devoted merited attention to the development of biological problems. He formulated the precepts not only in respect to the protection of man in space flight from the unfavorable effects of acceleration and weightlessness, but also expressed the ideas concerning the development, on interplanetary rockets, of a closed ecological life support system.

At the basis of his creative quests for the development of life support systems, i.e. of an artificial system for the circulation of materials, assuring the optimal conditions for man's and animals' existence both for prolonged habitation in spaceships as well as for dwelling on the Moon and planets, he placed the classic position of natural science concerning the unity of an organism and the environment.

In the designing of the life support systems, it is conventional to distinguish three groups of factors:

--the factors characterizing outer space as a unique environment for living (vacuum, ionizing radiation, meteorites),

--the factors associated with flight dynamics (acceleration, vibration, weightlessness), and

--the factors occasioned by extended sojourn in the artificial gas medium of a small, sealed cabin (isolation, hypokinesis [limited state of movement], emotional stress, altered biorhythm, microclimate, etc.).

Even this brief listing of the basic factors in a space environment indicates the unique complexity of the formation of the optimal, most favorable conditions of man's living away from Earth.

Under the effect of the extremal influences, i.e. those extraordinary in /98
force, compatible with the normal life activity of an organism, there originates an adaptive rearrangement of the functions, which expands somewhat the limits of the organism's existence, leads to a displacement of the optimum zone and a weakening of the dependence on the external conditions. As a result, a new functional level of vital activity appears, predetermining the new features of an organism's reaction both to the direct extremal influence (depending on the force, frequency, duration and intervals between influences, etc.) and in the period of the restoration of the functions to the original level (the after-effect). The latter reflects the combination of the catabolic and structural changes and acquires the significance of an important integral index, aiding one to judge the functional state of the regulatory systems,

the reactive capability of the organism, and its potential compensatory abilities.

The more intimately the function of any given organ is controlled by the higher sections of the central nervous system (CNS), the more rapidly and significantly the variations are manifested and the less the time that is spent in their restoration to the original level. The functions which to an appreciable extent depend also on the humoral (fluid) control mechanisms, especially those whose regulation involves the links of the peripheral (highly autonomous) intraparietal nerve devices, are distinguished under the same conditions by relatively high stability. But no matter how quickly their changes set in, they are differentiated by a rigidity of displacement, i.e. by a prolonged after-effect, typifying the development of the vegetative disruptions of individual organs even within the limits of a unified functional system. For example, under specific conditions of the influence of hypoxia or of transverse accelerations (8 g with a duration of 3 min.), the bioelectrical activity of the brain and heart (EEG, EKG) is restored within several minutes; for the activity of the gastric glands, several hours are required; judging by the modifications in enzyme activity, for the enteric glands restoration was achieved only after several weeks. It may be that the after-effect reactions of varying duration for various organs provide a con- /99
cept of the correlation of an organism's functions and promote the manifestation of latent, well-compensated effects of the influence of stresses in the absence of acute reactions. Evidently the relative state of constancy, of the dynamics of the cortical processes under the indicated conditions, is accomplished by unique protective mechanisms and by the sub-cortical centers of vegetative and neuroendocrinal regulation, which in this connection attain a higher stress limit, often exceeding the norm.

The presence of a unified system of control and communication in the living organism assures both the most optimal local modifications, and a general rearrangement of the entire organism against the background of adaptation to the given influence. The realization (during flight) of the activity level most advantageous for the entire organism under conditions differing from the normal ones is accompanied by an entire series of transient states. During the flight, we can observe periods of expressed discorrelation of functions when the autonomy of the individual systems increases abruptly. However, in the final analysis, the adaptation process is oriented toward the subordination of the specific to the general. In this context, the higher control levels can retain their normal functional ability owing to the extreme stress of the lower levels.

The balancing of an organism with the environment proceeds dynamically and is accomplished by the continuous liberation of energy; metabolism constitutes the source of this energy. With the disruption in an organism's functions, possible under the conditions of the extremal influences of space environmental factors, disruptions can also develop in metabolism, in energy exchange and the elimination of toxic metabolic products from the organism, which is linked with the changes in the optimal conditions of the vital activity of cells and tissues. As a result, the cellular elements are made vulnerable and the functional progressively increasing displacements can lead to the pathology of the organism as a unit. From this, we see how important it is, under the conditions of extremal influences (for purposes of health protection) to avoid the disruption and exhaustion of all levels of the nervous and humoral regulatory systems. /100

The most important significance in providing the coordination of the functions vital to an organism's life under changed conditions of existence is acquired by the relative constancy of the internal medium of the organism, characterized by the stability of the physiological, biochemical and other "constants", such as body temperature, osmotic pressure, active reaction of the blood, exchange processes, concentration of blood sugar, ionic composition, arterial pressure, etc. The relative constancy of the internal environment permits the organism to withstand considerable changes in the external environment and thereby to maintain equilibrium between them.

The maintenance and preservation of the relative constancy of functions, i.e. of the homeostatic reactions of an organism constitute the primary and indispensable condition toward which the close cooperation of biologists, physicians, engineers, physicists, chemists and specialists in other branches of knowledge is directed in designing space life support systems and space suits for various purposes.

Among the many problems associated with the practical development of life support systems, the leading one is that dealing with the formation of a gas environment and the control of its parameters.

The first life support systems for stratonauts, developed in our country in connection with the flight on 30 September 1933 of the stratosopheric balloon *"Osoaviakhim"*, are of considerable interest from the historical viewpoint. These life support systems, developed by aviation doctors A. P. Apollonov, M. P. Brestkin, P. I. Yegorov, A. V. Lebedinskiy, A. A. Sergeyev, V. A. Spasskiy, and V. V. Strel'tsov, served as the basis for further improvement of the life support systems, initially for the sealed cabins in aircraft, and then also for sealed spacecraft cabins. In the same period, were also developed the first Soviet space suits, created by A. A. Pereskokov and Ya. A. Rappoport (the G.V.F. space suit), by Ye. Ye. Chertovskaya (the "CH-3") and by /101 A. I. Khromushkin and A. G. Boyko (TSAGI = N. Ye. Zhukovskiy Central Aerohydrodynamic Institute).

From the protective clothing worn during the flights into the stratosphere to the autonomous systems permitting the space walk by cosmonaut A. A. Leonov in March 1965--such is the path of the space suit's evolution.

Just as more than 3 decades ago during the flights of the stratsopheric balloons, the Soviet spaceships *"Vostok"* and *"Voskhod"* were also provided with a two-component gas environment, consisting of nitrogen and oxygen, with the maximal similarity between its parameters and surface parameters. Under the conditions of orbital flights, this principle has fully justified itself.

The proper choice of the gas environment is connected with the solution of a major physiological dilemma. On the one hand, breathing pure oxygen, expecially under the conditions of acceleration forces exerted on the organism, promotes atelectasis, i.e. a collapse of the lung areas, but on the other hand, it favors the healing of decompression disorders. The question is far from resolved as to what extent nitrogen is required for the sustenance of life and whether its replacement by helium affects unfavorably the state of an organism's functional systems.

It goes without saying that the attempt to develop optimal physiological-hygienic comfort for the cosmonauts is closely allied with developing the systems of a conditioned gas environment in the cabins and space suits (temperature, humidity, purification from chemical, bacterial and other admixtures).

Here, we feel impelled to indicate that the problems of the influence of the habitation environment, of accelerations and weightlessness were brilinatly reflected in Tsiolkovskiy's reports.

The organisms of animals and man adapt to the conditions of Earth existence, to the conditions of terrestrial gravitation, developing an acceleration of 1 g (9.81 m/sec^2). However, a pilot in flight is subjected to the effects of high accelerations, and under certain circumstances, to a value of less than 1 g or partial weightlessness; in space flight, a cosmonaut is exposed to complete weightlessness. Perhaps acceleration as an environmental factor occupies a special place, since both increased and decreased gravitation can /102
represent physiological irritants that are extraordinary in force.

In the solution of the problem of the effect on an organism of the acceleration which differs in level and direction, primary significance must be given to strict allowance for accumulating interrelationships among the organism's functional systems and the characteristics of the influencing irritant.

The various systems have a dissimilar functional mobility in connection with which, along with a study of the cardiovascular system, the respiratory system, the CNS, and the systems of biologically active substances (acetylcholine, adrenalin, noradrenalin, histamine, and serotonin), we have also diverted attention to the state of the neuro-glandular apparatus of the gastrointestinal tract, as an important indicator of general physiological reactions.

Under the conditions of flight on modern aircraft, the crew often is in a state of great emotional stress associated with the responsibility, the specifics and the complexity of the tasks being performed in extremely short periods of time. The emotional stress, accompanied by an abrupt increase in the rate of breathing and of cardiac contractions may, in individual cases, even cause, due to hyperventilation, carbon dioxide shortage, decreased sugar content in the blood, and also insufficiency of oxygen utilization by the organism's tissues, above all by the brain tissues. A deterioration in the consumption of oxygen by the tissues also occurs under the effect of acceleration and other irritants.

The mechanism of the effect of acceleration is complex; above all, alterations in hemodynamics are detected. At acclerations which are appreciable in value, the phenomenon of circulatory hypoxia also develops (Ye. A. Kovalenko, V. L. Popkov, and I. N. Chernyakov), which aggravates the effect of the mechanical forces. Since the various tissues or organs of the intact organism have varying sensitivity and stability to hypoxia, to some extent /103 this will determine the integrated response reaction of the organs during acceleration, especially in the period of after-effect.

One of the first, most typical manifestations of the effect of acceleration is the disruption of the permeability of the vascular wall. This is evidenced above all by the yield of regular elements through diapedesis, which is also typical of actue hypoxia. As we have already mentioned above, acceleration causes oxygen-deficient states and it may be that under specific conditions and at certain stages, acceleration and hypoxia may act together.

Acceleration causes a redistribution of the circulating volume of blood; moreover, its greater part is accumulated in those parts of the body or organ which experience the maximal effect.

Independently of the direction of the effect of accelerations, in the blood we find manifest changes in the content of biologically active substances, i.e. of acetylcholine, serotonin, histamine, adrenalin and noradrenalin, which evidently is the general adaptive reaction for the control of the vascular tonus. At the same time, the data characterizing the changes in the content of histamine and diaminooxidase, and also of adrenalin in the brain tissues, lungs and the mucous membrane of the intestine, indicate that acceleration exerts an effect on the flow of the metabolic processes in the tissues themselves. Even under one-time acceleration on the order of 10 g with a duration of 1 min. and 8 g lasting for 3 min., from head to feet, a prolonged after-effect occurs, which is doubtless connected with the combined influence of the hypoxic factor and structural disruptions in the tissues.

V. G. Yeliseyev established that during accelerations (8 g for 3 min., direction from chest to back) in test animals (a dog and monkey), morphological disruptions develop in the tissues of the brain, spleen, lungs, kidneys and pancreas. The main modifications in the pancreas are linked with disorders of the blood circulation.

In the first days after the acceleration, there occur polyemia, atelec- /104 tasis and hemorrhage both by way of diapedesis and as a result of tissue rupture. In the subsequent periods, we have the development of inflammatory phenomena in the lung tissue, while in the late periods (15 - 60 days), we have focal sclerosing of parenchyma as a result of the previous hemorrhaging or the onset of pneumonia. One should emphasize particularly that the changes described do not appreciably affect the breathing function and have adequate compensation (Yu. N. Korolev).

Expressed disruptions in the tissues of animals (mice and guinea pigs) returned from orbital flight were established by V. G. Petrukhin. In almost all of the organs (brain, lungs, heart, liver, piece of liver with pancreas, kidney, adrenal glands, spleen, testes, thyroid gland), he found significant changes of varying nature depending on the periods having passed since the flights. Thus, in the animals killed after two days of flight, there were residual phenomena of blood circulation disorder, Considerably greater changes were found in the ganglionic cells; in the cerebral cortex, most often subjected to changes were the ganglionic cells of the occipital parts and areas of the *gyrus centralis;* at 10 days after flight, the ganglionic cells were in various stages and forms of dystrophy; by the end of 30 days, the number of damaged cells decreased; residual phenomena were also observed for up to 60 days. The liver's structural disruptions were also healed after 60 days. This is the general period (according to the data of morphological analysis of the brain and liver tissue) of the after-effect in animals subjected to the influence of environmental factors under actual conditions of space flight.

In the studies conducted by M. I. Razumov and I. M. Khazen, using animals under conditions of transverse acceleration (8 g for 3 min.), pathomorphological changes of the internal organs (lungs, heart, kidneys, adrenal glands, liver, stomach, small intestine, and pancreas were also noted. /105

After single acceleration, abrupt disruptions in the formation of enzymes in the neuroglandular apparatus of the digestive system, were also noted, which was reflected in disruptions in protein synthesis.

The data from histochemical studies also gave evidence of the possibility of the disruptions in protein synthesis. Damage to the intracellular structures of the epithelium of the liver is expressed in the displacement of nuclei in the cytoplasm and disorders in the chromatin of the nuclear substance. As a result, we have a disruption in the proper flow of protein synthesis, which is deposited in the nuclear substance, forming large prismatic crystals. The disturbance in protein synthesis in the epithelium cells occurs on the third day after the effect of acceleration. It does not include all the cells, but only those located in the internal sections of the liver lobules. Under the effect of accelerations, we also note changes in the fatty aspects and in certain other aspects of metabolism.

The materials cited indicate how important it is to prevent or to alleviate the disorders in an organism, caused by extremal influences. In this direction, the research thinking has tended toward improving the design of aircraft and life support systems, along with improving all the functional systems of the organism itself and of the conditions of living away from Earth. Tsiolkovskiy was the first in the world to substantiate the idea of an anti-G suit of the hydraulic type. In Tsiolkovskiy's opinion, an important means of protection is the submergence of the body in a liquid of equal density: "Nature has long been using this method, immersing the embryo of animals, their brains and other weak parts in a liquid. Thus, she protects them from any damages".

Of particular interest is Tsiolkovskiy's suggestion to impart a reclining position to man during the launching of a rocket. In the usual working posture of a pilot, the centrifugal forces operate parallel to the large vessels, from "head to feet". Under these conditions, accelerations of 7 - 8 G lasting for 10 - 15 seconds can evoke appreciable disorders in the organism. It is therefore most efficient to alter the direction of application of the centrifugal forces. Acceleration operating in a direction perpendicular to the body's longitudinal axis imposes a lesser load on the system of blood /106 circulation. Proceeding from this, in order to raise the tolerance to acceleration, the proposal was made to have the pilot assume a more horizontal position (N. M. Dobrotvorskiy). In conjunction with the preliminary special types of preparation and training, the physiologically optimal pose assumed by an organism during the takeoff of an aircraft will favor the preservation of homeostasis; this is uniquely important since its disruptions can predetermine the general resistance of the organism, its reactivity to living under conditions of weightlessness. Using the proper theoretical approach, we can predict the course of the physiological processes and control them for the support of the organism's homeostatic functions, and thereby maintain working capacity and health.

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PSYCHOLOGICAL FACTORS OF PROLONGED SPACE FLIGHTS /108

B. S. Alyakrinskiy

It has already currently become evident that man will be an indispensable participant in practically any prolonged flight into outer space. His participation in such flights is determined primarily by the ability, inherent only to man, to solve creatively any urgently developing problem connected with the safety and effectiveness of a spaceship's flight. Moreover, if we take into account man's high reliability as a link in a closed system for the control of a spacecraft and his innate stable tendency toward understanding more manifestly, the more unusual and more complex the object, we can see clearly the significance of a scientific analysis of man's psychological reactions to all conditions of prolonged space flight.

Such an analysis forms the content of one of the newest sciences, which was born at the threshold of the space age, i.e. space psychology.

The basic trends in research within the scope of space psychology are established by the features of the conditions of life and activity of man in space. Among these conditions, the most important significance accrues to: modified--increased, decreased and zero--gravitation; the scarcity of sensory impressions, or sensory deprivation, sensory inadequacy, or sometimes its unusualness and excess; isolated state and confinement in a small space: novelty and unexpectedness of situations in which the cosmonauts find themselves in various flight stages; the boredom and continuous contact between participants in the space flight; the appreciable and continually increasing separation of the cosmonauts from large human groups; the differing (as compared with the Earth conditions) so-called time cues, i.e. agents signalling the start of given periods of days, primarily work and rest periods and, /109
finally, the unusual combinations and unusual intensities and duration of the effect of a number of factors also occurring under ordinary conditions of man's life (noise, vibration, radioactive radiation, temperature fluctuations, etc.).

Among all of these conditions of prolonged space flight, the most specific for it and the least customary for man is weightlessness. Even prior to the first orbital manned flights, and especially intensively after the fulfillment of the first such flights, a study began of the problem of the influence of weightlessness on man under various experimental conditions, simulating to a greater or lesser extent the actual factor existing in space flight. Tests were conducted on experimental subjects located in small cabins, in special chairs, under the observance of strict bed rest, during submergence of the subjects in water or in various solutions, with the use of the lift effect (in ordinary and express elevators, in falling capsules and containers, during parachute jumps), during the flight of aircraft along a ballistic curve (the Kepler parabola or the weightlessness parabola), and under conditions of orbital flights of single- and multi-place spacecraft.

The data collected under such diverse conditions are not of equal value, and many of them characterize only vaguely the effect on the human organism as a whole and on his psychics in particular of the force field of an actual space flight. However, many of them have unquestionable scientific value within the framework of space medicine and space psychology. Among the data of this type, let us note first of all those which typify the motor activity of man, the features of his motor coordination during a change (in any direction and by any amount) of the gravitational force, constantly participating in the construction of each motor act of man "on Earth".

The disruption of senso-motor coordination in the state of hypodynamia as a rule is combined with a decline in the general mental work capability and by a deterioration in such mental functions as perception, thinking and attention.

It is interesting that artificial hypodynamia exerts a negative effect on the most important intellectual and senso-motor functions of man. However, the simulation of weightlessness does not provide an adequate representation of the conditions of space flight and does not allow the direct use of the /110
derived facts in the organization of actual space flights.

The best simulation of "space weightlessness" is attained in flights on specially equipped aircraft along a ballistic curve, in a certain sector of which dynamic weightlessness develops for several tens of seconds. In such flights, facts have been accumulated permitting one to represent fairly completely man's mental state in a field of zero gravitation. It was noted that in the test subjects, the transition to a weightlessness state disturbs motor coordination and spatial orientation.

Thus, the famous American test pilot C. Eager after 8 - 10 seconds' sojourn in weightlessness lost spatial orientation and departed from the parabola.

Along with this data, a number of researchers report low tolerance to weightlessness of subjects during flight over a Kepler parabola.

There is good reason to believe that the divergence of views relative to the nature of the effect of weightlessness on man's mental work capacity is explained both by difference in the procedural approaches to the solution of the question, as well as by the current neuro-psychic and somatic state of the test subjects at the moment of the experiment and (which evidently is most important), their individual differences, according to which all the test subjects can be divided into 3 categories of persons: those who withstand weightlessness well, satisfactorily and poorly.

The researchers, in classifying the persons subjected to weightlessness into 3 groups (indifferent, positive and negative tolerance to weightlessness) note that in the representatives of the last group, in certain instances there develops the illusion of falling, accompanied by a feeling of horror and high motor activity. Such subjects are completely disoriented in space, lose contact with the people nearby; their reaction is reminiscent of the "destruction of the world" syndrome, widely known in clinics of mental disorders.

The tests under Earth conditions, and flights along a ballistic curve constituted an important and necessary stage in man's preparation for space flights and above all for orbital flights. In the process of orbital flights, experimentation succeeded in refining the data typifying the mental reactions of man to weightlessness. Yu. A. Gagarin reported that during the entire flight, his feeling of well-being did not worsen. G. S. Titov retained a satisfactory capacity to do mental work during the flight. A. Shepard and /111
J. Glenn, the American astronauts, withstood the state of weightlessness well, while Carpenter called the state of weightlessness "bliss--nothing more nor less". The same experience of weightlessness was evoked in G. Cooper, V. F. Bykovskiy and P. R. Popovich who evaluated their feelings as excellent. However, not all of the cosmonauts tolerated the state of weightlessness so well: in B. B. Yegorov and K. P. Feoktistov, it caused a certain disruption of their somatic and neuro-mental well-being (according to subjective data provided by these cosmonauts). P. B. Miller reports that during the attempts to set a mobile light beam horizontally in accordance with the subjective perception of the vertical during the Gemini-5 flight, G. Cooper made an error of 32°. An analysis of the handwriting of V. F. Bykovskiy and V. V. Tereshkova (A. I. Mantsvetova et al.) indicated that their coordination of movements during writing varied within limits of more than the average or less than the average level of coordination diminution.

The weightlessness problem is closely related to the interesting and important problem of the sensory security of man under space conditions. It was established long ago that the optimal level of man's mental work capability is safeguarded only if his sense organs impart to him a certain minimum of impressions. A reduction in the general flow of these impressions below a minimum leads to a decline in the mental tonus, to a disruption in the normal function of the higher sections of the CNS. Such a state is said to be sensory hunger (sensory inadequacy, sensory deprivation, a deficit of afferentation). An analysis of the conditions of prolonged space flights permits the assumption that sensory hunger can occur at many stages of such flights. O.N. Kuznetsov and V. I. Lebedev have concluded that in a number of test subjects, under conditions of isolation and the associated impoverishment of external impressions, illusions developed such as errors in recognition, eudetic representations, a feeling of the presence of another person, dreaming accepted as reality, ideas of relation and hyper-valued ideas. In a large number of tests on the study of sensory inadequacy, the test subjects showed a decrease in the capacity for mental work, of self-criticism, of interest in study, indifference to surroundings, a retardation of actions (N. A. Agadzhanyan, A. G. Kuznetsov), a lengthening of the latent periods of motor reactions (F.D. Gorbov and others), a decrease in ability to perform complex mental operations, the presence of visual and proprioceptive hallucinations (Khoti), disturbance of sleep, a deterioration in operational memory (L. A. Sivokon'), difficulties /112
in the accomplishment of complex sensomotor tasks (S. G. Zharov et al.),

appreciable disorders in determining elapsed time segments (Hanna, Levy), the appearance of nonmotivated states of excitation, a marked manifestation of unusual personality features (O. N. Kuznetsov), increased sensitivity to remarks made by others, and a nonobjective evaluation of the behavior of comrades in the test (Ye. Gunderson). All of the listed occurrences were more manifested with clearly monotonous state of activity, slight activity of the test subjects (Siril) (Cyril), a decrease in the informative state of the sensory irritants (M. I. Bobneva), an impoverishment in the motor activity (B. A. Lampusov), a prolonging of sleep or a disruption of the usual regime of work and rest(O. N. Kuznetsov et al.).

The studies made by neurophysiologists in recent decades have revealed the mechanism of sensory deprivation. As it turns out, the reduction in the mental tonus with inadequacy of sensory impressions is determined by the functioning of a special nerve structure, localized in the subcortex, which is called the reticular formation. In the area of the reticular formation, many branches (collaterals) enter from the main neural arteries, connecting the receptor devices of the analyzers with their final stage, i.e. with the cortical cells. Along these collaterals to the reticular formation, there passes a certain amount of nervous energy from any specific afferent flow. The cells of the reticular formation transform this specific afferentation and then direct it to the cortex of the brain's major hemispheres, in the form of nonspecific afferentation, which fulfills the function of a stimulator of the cortical cells. A cortical cell, just as any nerve cell, can begin its work in response to an afferent excitation, can acquire new rhythms and can provide excitation only in the event that it has already been "swayed" by some preliminary influences. This "swaying" effect on the cortical cells is also exerted by the nonspecific pulsation proceeding from the reticular formation.

The manifestation of sensory deprivation has a distinct individual nature. In this respect, all persons can be divided into 3 groups.. those withstanding sensory deprivation badly, indifferently and well. There are grounds for assuming that the reaction to a reduction in the overall level of afferentation depends to a considerable extent on certain general features of a subject's mental activity. There are people who require a high stability and wealth of external impressions, make rapid and good contact with the group /113
surrounding them, are bored by loneliness, are not distinguished by the ability for self-absorption; for them, speaking metaphorically, the center of crystallization of mental activity lies somewhere in the surrounding environment. In contrast to them, there are people of another mental makeup, usually making little or slow contact with other people, with a well-developed ability for introspection, with a tendency toward self-analysis and loneliness. Using the same metaphor, we can say that the crystallization center of the mental activity of such subjects lies within themselves, in the realm of their experiences. Persons of the first type are called extrocentric, and persons of the second type are said to be introcentric. It can be thought that a tendency toward introcentrism is a favorable trait in the personality of a candidate for prolonged space travel.

Selection based on the criterion of introcentrism facilitates the resolution of the problem of the sensory insufficiency in space only partially. Among the suggestions for the reduction of the detrimental effect of this factor, we should include: the saturation of the environment, surrounding the astronaut with stimulants having a high informative value, the resemblance of the composition and level of intensity of the sensory background of the spaceship cabin to the usual "Earth" background, a fairly frequent change in the types of work, and possibly more precise information concerning the time of day on board or Earth time).

Man's isolation in the cabin of a space vehicle of any type is not the only danger associated with the danger of sensory deprivation. In certain individuals, confinement in the small enclosed area in such a cabin can cause a special state, called claustrophobia.

Claustrophobia is a sickness caused by closed spaces. It relates to a number of obsessive states, of obsessive fears. A man subject to claustrophobia, when confined to a closed place (especially a small one), fears the loss of consciousness, feels ill at ease; he experiences fear of varying degrees, and at times is extremely fearful. Considering the question of the screening of candidates for prolonged space flights, Kenneth E. Pletcher writes: "In some candidates, the required psychological adaptation needed to be confined in a tight suit and moreover to wear a helmet with a tight neck fastening, was lacking...one even showed signs of expressed claustrophobia. He acquired a state of abrupt alarm after putting on the space suit".

From the psychological standpoint, the difficulties of adaptation to /114
small confined spaces are not exhausted by the risk of sensory deprivation and claustrophobia in the case when several men must live in such small spaces. In this respect, the experience gained in organizing prolonged periods of wintering-over in the Arctic and Antarctic, the life of small groups under conditions of expeditions, on submarines and in other analogous conditions is worthy of considerable attention.

In the Soviet Union, since 1960, a number of researchers headed by F. D. Gorbov has been working on the problem of the compatibility of people in small groups. According to the original position of these researchers, any group of people can be regarded as a separate social unit; its structure and features determine to an appreciable extent the specific importance of each of its participants. The state of the members of such groups becoming accustomed to one another is directly dependent on the mutual balance, the mutual understanding of the life and professional strategy and tactics, and of the actual potentialities of all members of the group.

The problem of people becoming used to each other and working harmoniously in small groups is directly contiguous to the problem of organizing the conditions of the work and rest of such groups. Under the conditions of space, the organization of the life rhythm on board the spacecraft or at the planetary bases has a uniquely important and independent significance. The questions of organizing the daily routine of work and rest for the cosmonauts comprise in essence the problems of a still relatively new science: biorhythmology. In the Soviet Union, the official "birthday" of biorhythmology was the day of opening the first domestic (Soviet) symposium devoted to the problem of biological rhythms and the organization of regimes of work and rest of man under various conditions, including extremal ones; the Conference met from 20 - 21 June 1967 in Moscow[1].

All of these problems in space psychology are being solved fairly successfully by laboratory experiments and full-scale experiments. There is, however, one problem, the study of which under these conditions is practically impossible. This is the problem of the mental reactions of man to danger, the problem of nervous-emotional stress in special cases, threatening one's well-being and even his life. In prolonged space flight, man will be continuously subjected to conditions fraught with elements of novelty and unexpectedness, many of which may conceal danger. The intensity of latent danger in space will increase incessantly in proportion to the distance from Earth; as /115 a result, the natural reaction to danger will be intensified by the so-called reaction of separation.

The analysis of the individual forms of man's reaction to hazard permits us to distinguish 3 forms: instinctive (innate) to a direct threat to life, caused by past experience (the conditioned-reflex form of fear) and intellectual, which occurs (or could occur) in all those instances when the danger is discovered by logical analysis of the situation, an understanding of the possibility of its unfavorable modification. It is apparent that under conditions in space, we will find most often specifically this (intellectual) form of fear. An astronaut moving impetuously away from Earth will clearly understand the result of any disruption in the integrity of the ship, a failure in the life support system, etc. This understanding can constitute the basis for caution, sometimes alarm, particularly in any cases when the functioning of any given system on the ship is disrupted in some way, or when a threat develops to the intact state of the spacecraft hull, separating the astronaut from open space, the conditions of which exclude completely the chance of even the briefest survival without special life support devices. On the basis of the intellectual reaction to danger, the attitude of the astronaut to the ship will be colored by a feeling of "confident intimacy" (B.S. Alyakrinskiy, 1962). In the system of relationships connecting man with a machine, depending on their value for man, we can differentiate as the most important the productive and viably-necessary relationships. In particular, the latter type of relationships is typical for the "pilot-aircraft" system. It will prove inherent even to a greater extent to the "astronaut-spaceship" system.

The general result of experiencing such states will be determined by the individual psychological features of the personality of future travellers in outer space.

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[1] Material added by the author during preparation of lecture for press.

Reactions to danger are experienced differently by different persons, apart from the dependence on their forms and internal mechanisms. In about 20% of people, danger, given its sufficient manifestation, causes a marked disruption in behavior, all the way to a state of emotional shock. This form of fear is justifiably said to be of an asthenic form. In 60% of people, danger, while lowering the over-all effectiveness of their activity, does not disrupt it sufficiently to exclude a logical and feasible reaction to the source of danger. This is the normosthenic form of fear. Finally, around /116
20% of people in a situation of threat to their life will manifest uniquely high presence of mind, ingenuity and tenacity. The representatives of this group prove to have more initiative and are more creatively productive under dangerous conditions than under ordinary circumstances. Such subjects have been called "lovers of risk", of acute sensations, and their experience can be called a combat stimulation. In particular, the problem of the professional selection in the field of astronautics consists of the establishment of criteria for individual-psychological features of the reaction to danger. Among such criteria, we include the frequency of the pulse, respiration, blood pressure, amount of adrenalin in the blood, and other values characterizing the state of the vegetative functions and thereby the emotional sphere of man.

From the procedural standpoint, a quite complex problem is that of the reaction to alienation (loss of contact), i.e. of that state which develops in a man during his appreciable separation from large groups. The alienation reaction was initially described in the case of the stratonauts, who ascended to great heights in stratospheric balloons. The symptoms of the alienation reaction are inward stress, alarm, sometimes a feeling of helplessness; on the other hand, in some cases one finds a feeling of elation and a desire to continue the flight. Under Earth conditions, it is not possible to reproduce the situation of reaction to alienation, because only in space does it develop in its "pure" form. In all other cases, man, even though considerably separated from society similar to his, will either remain under conditions of constant alienation from it, or will actively overcome these conditions, whereas in space, the separation from the group increases continuously, and at an appreciable "cosmic" velocity. However, here also the indirect approaches can aid in establishing certain points of departure for a system for professional selection and training of candidates for prolonged space flights. There are grounds for postulating that an introceptive type of subject, i.e. one with the ability for self-meditation, and a tendency toward a concentrated prolonged internally oriented attention, is less inclined toward experiences such as alienation reaction than the opposite type of extroceptive persons.

Such are the most significant problems of space psychology, which, still constituting a very recent branch of human knowledge, has permanently taken its place among the ranks of sciences supporting the realization of one of the most grandiose tasks ever having stimulated man's thinking, namely the task of conquering the vastness of the Universe.

THE DEVELOPMENT OF TSIOLKOVSKIY'S IDEAS CONCERNING THE SETTLEMENT OF SPACE /117

A. T. Ulubekov

Since the 4th of October 1957, the word "Sputnik" became widely accepted in man's vocabulary. In various countries, it is pronounced with different accents, but with the same feeling of respect for the force of human labor and intelligence.

The subsequent successes of practical astronautics, having been crowned with the emergence of man into space beyond the atmosphere, with the sending of an automatic spacecraft to Venus and Mars, with the soft landing of a scientific vehicle on the Moon and with the development of lunar satellites, furnish a basis for stating that the period of the activity of man on the cosmic scale has commenced. The tempestuous process of the conquest of space is a distinguishing feature of our age.

The developer of astronautics and the theory of rockets for space purposes, namely, K. E. Tsiolkovskiy, profoundly analyzed almost all of the essential questions connected with the conquest of space by man.

One of the major achievements of the successors of Tsiolkovskiy is the development of automatic interplanetary spacecraft and satellites of celestial bodies, which has become possible in connection with the appearance of electronics, automatic devices and TV.

The problems of the conquest of space in the next 1 or 2 decades are sufficiently clear from published materials. They can be reduced to the following:

1. Scientific investigations of world space and of celestial bodies (including the undertaking of experiments under special conditions and the support of the prolonged stay of man beyond the limits of Earth).

2. The use of space technology and extraterrestrial resources for the practical needs of the Earth's population (remote radio and TV communication, predicting and controlling the weather and climate, ultra-fast intercontinental transport, etc.).

The technical means for the solution of these problems are also quite specific: These are the artificial satellites and permanent inhabited circumterrestrial stations, automatic interplanetary spacecraft, interplanetary manned spaceships, and scientific bases on the moon and planets. /118

An analysis of the objective need for the conquest of space, determined particularly by the need for the development of science and production, is given in a report by Ye. T. Faddeyev (refer to the collection "Dialectical Materialism and Problems of Natural Science", Moscow State Univ. Press, 1964) and A. D. Ursula ("Certain Philosophical Questions of Space Conquest", *Znaniye Press*, 1964).

An outstanding contribution to the solution of individual stages in the problems of space conquest has been made by our Soviet scientists and designers. In our times, considerable attention is beginning to be paid to the potential questions of the mastery of the power and raw material resources of the solar system.

To Tsiolkovskiy, we accord preeminence in the clear scientific formulation and partial development of the problem of the necessity and possibility of conquering ever-wider expanses of the universe for the life of developing mankind.

In connection with this problem one should obviously examine the condition and the order of development of the following questions:

1. The need for the use of the resources in the solar system by man.

2. The feasible ways and forms for the use of the material and energy in space for space settlements.

3. The possibility of the permanent dwelling of people away from Earth.

Tsiolkovskiy, in a number of his reports ("Study of World Spaces by Reactive Devices", 1903, 1911-1912, 1926 editions, "Purposes of Stellar Navigation," 1929, and others) indicated certain conditions compelling man to turn to the use of the inexhaustible extraterrestrial resources, Among these conditions, he includes: a) the limited state of the terrestrial area and power resources with the unlimited growth of population; b) the guarantee of the survival of man in the case of a catastrophe on Earth (geologic changes, collision with an asteroid, etc., c) the advantages of life in "ethereal" cities of circumsolar space (the presence of colossal solar energy, optimal conditions of life in an artificial living environment, the absence of the "chains" of gravitation, etc.).

As early as 1903, when he published his classical "Investigation", Tsiolkovskiy understood its basic importance for future mankind; in a letter /119
to the editor of the journal *Nauchnoye Obozreniye*, M. M. Filippov, he wrote: "Almost the entire energy of the sun is now useless for man, because the Earth receives two (more exactly 2.23) billion times less than the sun radiates. What is strange in the idea of using this energy? What is strange in the idea of mastering the limitless space surrounding the Earth?....[1, p. 244].

Later, Tsiolkovskiy returned repeatedly to the problem of the conquest of world space and expounded a plan of the stages of this conquest, including the conquest of the regions of the neighboring stars (see, for example, "Purposes of Stellar Navigation").

The question of the settlement of space can be considered from three standpoints:

a) it is not needed by man;

b) it will prove desirable;

c) it will be inevitable in connection with the continuous increase of the productive forces and the quantitative rise in the population.

We will present ideas testifying to the validity of the third position, although it still requires rigorous proof by philosophers and sociologists.

Is the quantitative growth of humanity dictated by the requirements of the progress of our civilization? If the answer be affirmative, the involvement of extraterrestrial resources will become necessary; are there still other causes (other than the rise in population), for the inevitability of space settlement?

Academician S. G. Strumilin considers that the conquest of space is not required for the life of man, since at the attainment of a critical longevity, the values of the birth rate and mortality tend to equalize, and in case of necessity, means will be found for controlling the increase in population [2]. In our opinion, this tendency only indicates that, in proportion to the approach of the average life expectancy to the critical one, we should expect a decrease in the presently rising rate of population growth. An evaluation of the population of future mankind can be made only in consideration of its relationship to the progress of society.

However, we see clearly that a cessation of the population growth would retard appreciably the development of civilization, since progress is inconceivable without a growth in the productive forces; however, their most important component part is comprised of people controlling the tools of production. Hence, unlimited progress also requires a continuous growth in population (but of course, at a lesser rate, owing to increased automation). /120
It is quite indisputable that no matter to what extent physical labor is eased by scientific-technical means, the physical participation of man in the production process will remain inevitable.

According to the statistical data of the last century, and contrary to the predictions of the proponents of Malthus, the output of production, including food, can increase at higher rates than the population growth, while poverty and hunger are determined by social causes.

As K. M. Malin has demonstrated convincingly, the utilization of additional land, of leading experience and scientific achievements will provide an important growth in the production of agriculture and animal husbandry, and also the production of food on Earth at scales necessary for feeding several hundreds of billions of people adequately. [3].

The natural question arises: Are there any basic difficulties in the provision of power and material to such a population for a prolonged period?

As concerns the question of the raw material resources of our planet, including the resources for the production of industrial output and food, they surpass by several tens of millions of times the reserves required by the population on Earth [3].

The matter is much more complex in connection with the power supply to the growing populace and its productive forces; here we find several interesting and important questions.

It is natural that the development of production, and primarily of power, should always proceed at somewhat more rapid rates than the population growth. Unfortunately, the rise in the output of power leads to a corresponding change in climate, since, as a result of its utilization, most of the energy enters the atmosphere as heat.

In order that the temperature of the atmosphere and the Earth's surface might remain within acceptable limits, the amount of energy which is being developed by man (for terrestrial use) should not exceed 10% of the solar energy incident to us. In this context, as we can easily determine from the equation of the Earth's heat balance, the average temperature of the Earth's outer mantle would rise by 7°; at an energy production level amounting to 20% of the incident solar flux, the corresponding increase in temperature would reach 13°.

At the present time, the world consumption of power is about $3 \cdot 10^9$ kw; /121
the solar radiation being absorbed by Earth equals about 10^{14} kw. Thus, an increase in the development of power by 3,000 times to the value of the permissible limit (10^{13} kw) is possible. Assuming that the annual increase in the power output averages 3%, we find the period of the limitation of its growth to be approximately 270 years.

However, we can use a part of the solar energy incident to us for power requirements without loss of thermal equilibrium. Still, this use evidently will not exceed 20- 30% of the solar energy incident to Earth, since approximately half of it is expended in the evaporation of water and the ascent of vapors into the atmosphere.

Thus, the use of solar energy for the requirements of power engineering leads to an increase in the critically-permissible terrestrial energy resources of 2 - 3 times more, i.e. the energy consumption can be increased in relation to the present level by about 10,000 times, which lengthens the growth period in power consumption by several decades more.

Let us proceed to the question of the feasible approaches and forms for the use of extraterrestrial resources.

Let us consider briefly what the situation is as concerns the power-spatial and raw material potentials of the solar system. The area of the sphere surrounding the Sun at the distance of the Earth is 2.2 billion times greater than the area of the cross-section of our planet and thus receives this much more solar energy than the Earth. However, since the Earth's surface and the clouds reflect around 40% of the solar energy into interplanetary space, the full light from the sun exceeds by 3.5 billion times that which reaches Earth.

Solar energy is a powerful and practically inexhaustible source, because the Sun will last for another 5 - 10 billion years with an almost unchanging intensity of radiation, according to modern concepts.

The material resources of the solar system are basically concentrated in the sun and the planets. The use of solar material for non-power purposes is evidently excluded, not only because it consists almost entirely of hydrogen and helium (and is not accessible), but also because a variation in the mass of a star significantly changes its luminance and evolution.

On the other hand, as will be shown later, it is also unfeasible to make /122 large scale use of the planetary masses for power requirements. The material of the planets will serve as a base for building various extraterrestrial structures as minerals for production, and raw material for the growth of the animal and vegetable world. Other celestial bodies will also find application (asteroids, satellites of planets, meteorites and comets), but their role generally can be significant only in the first stages of the conquest of outer space.

The mass of the planets of the solar system is larger than the Earth by 450 times (and with allowance for the smaller bodies, by about 500 times); their surface exceeds the Earth's surface by almost 250 times.

In the immediate decades, we obviously will achieve the visitation of planets by people on scientific missions. However, as yet there is no direct possibility of populating any of the planets, owing to the lack of conditions necessary for maintaining human life.

The force of gravity on the planet's surfaces (except Jupiter, where it exceeds Earth gravity by 2.6 times) is either close to that on Earth, or slightly less.

In our view, the most important factor determining the possibility of extra-terrestrial colonization is the intensity of the incident solar energy which is established by the distance from the Sun. In this sense, most of the planets differ sharply from ours (see Table):

Value of Solar Flux to the Planets a Compared with Earth Level

Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
6.6	1.93	1	0.43	0.037	0.011	0.0027	0.0011	0.00065

In connection with the slight energy flow to the planets remote from the Sun (Jupiter, Saturn, etc.), the temperature of their outer layers is extremely low, i.e. of the order of -150 to -200° C, so that very high power expenditures are required for a prolonged sojourn on them.

If we make the pertinent calculations--proceeding from ratios similar to those on Earth--the raw materials on these planets, used in the thermonuclear process, would satisfy their power requirement for about 5 million years.

The conquest of Mars and Venus for colonies could support a further /123 population increase in mankind by 2 - 2.5 times. However, if we can succeed in overcoming the power (and other) difficulties in the settlement of the remote planets, the human population could increase by about 100 times (in proportion to the surfaces of the planets which are being used); with consideration of the conquest of the remaining planets in the solar system, it could increase by 200 - 250 times.

Immeasurably great potentialities in this respect could be realized by the conquest of circumsolar space, owing to the more efficient utilization of the material of planets, and of solar energy.

As early as in the "Investigations..." of 1911-12, Tsiolkovskiy wrote: "There is no need to be on the heavy planets, even for study. They are difficult to reach; to live on them would mean to be attached to them by the chains of gravity, sometimes more powerful than on Earth..." "Mankind will launch its rockets to one of the asteroids and will make it a base for the initial operations. He will use the material of the small planetoid and will analyze or dissociate it to the center for the erection of his structures, forming the first ring around the Sun". "The force from the Sun's rays can be used for existence throughout an indefinitely long time without an atmosphere and a planet. As the Earth's atmosphere is cleaned by plants with the aid of the Sun, we can also renew our artificial atmosphere. As on Earth, the plants absorb with their leaves and roots the impurities and yield food in exchange, the plants taken with us can also function continually on our behalf... As on the Earth's surface, the endless mechanical and chemical circulation of material will be achieved, it will be accomplished in our small world" [4, pp. 196, 195, 197].

The planets' deep masses are practically inaccessible owing to the very high temperatures and pressures (e.g., for Earth a penetration of 1 km yields a temperature increase of 30°), not to mention that their extraction leads to a disruption of the remaining thin-walled mantle. Thus, from the planets we can use only a thin surface layer of matter, and we can exploit only the solar energy impinging directly on the surface.

Currently, we are using less than one hundred millionth of the Earth's mass [5], which, when converted per inhabitant, yields a mass of substance equalling 20,000 tons. If we assume this ratio to be half as much for space dwelling environment, and weightlessness), with full-scale usage of the sub- /124
stance of planets and of smaller bodies in the solar system, the present population of man can be increased by more than 10^{11} times, or can surpass by a billion times the maximum terrestrial population.

We wish to turn attention to yet another interesting and quite undeveloped question: Is it possible to have such a sophisticated organization of the circulation of matter in a sufficiently large "ethereal" city with permanent population that losses of matter will not occur? Or will its replenishment be required (and in what quantities) to compensate the losses occurring during certain physical, chemical and biological processes, transpiring with the release of energy?

The engineering feasibility of man's attainment of outer space and his life activity away from Earth were proved theoretically by Tsiolkovskiy as early as 1903, and by now it has been realized in practice. There is no doubt that in connection with planned flights of man to the Moon and to the planets in the solar system, coupled with the development of permanent manned spacecraft orbiting the Earth, measures will be adopted supporting many years' sojourn of man in space.

However, it is necessary to solve the question of the feasibility of organizing permanent colonies in space (e.g. in "ethereal" cities in circumsolar orbits).

Here, 3 major difficulties are involved: 1. the effect of weightlessness, 2. the influence of cosmic radiation and 3. the meteor danger.

As concerns the effect of weightlessness, it is apparently necessary to use the centrifugal effect for the creation of artificial gravity (to the desired extent); in this respect, much work is still ahead, but the solution of this problem does not present any major difficulties.

In our view, in overcoming the radiation and meteor dangers, appreciable aid could be exerted by experimental manned circumsolar satellites, the orbits of which are situated in different planes.

Some of them should be engaged in clearing circumsolar space of meteorite bodies; others should develop a design for space living quarters: they should have devices for the rapid restoration of pressure in depressurized facilities and a massive front section (most often encountering micrometeorites), which in the course of brief (but radiation-dangerous) solar flares, could be turned to serve as an appropriate shield from harmful radiation. /125

Without doubt, very great efforts will still be required in overcoming the radiation danger: obviously, in this respect a positive role will be played by drugs, the adaptation of many generations, the selection of materials for the structural walls, the orientation of the living accomodations in space, etc.

Let us dwell briefly on the following questions, also subject to further development: the organization (in space) of power engineering, of transport, industrial and agricultural production.

It is quite obvious that the Sun will constitute the main energy source. The use of solar energy in space does not present any difficulties; the methods involved can be quite flexible. They can involve either the direct absorption of radiant energy (for plant growth, heating of buildings), or its conversion to electric power (as in modern space equipment), or can consist of its preliminary concentration by mirrors (for the requirements of science, power engineering, industry), etc.

The development of industry and transport in outer space under conditions of weightlessness (or of slight weight), in the presence of powerful energy and a vacuum will obviously be quite successful.

Still more favorable conditions are at hand for the development of productive plants: it is easy to obtain the desired heat and light conditions, and composition and moistness of air in a greenhouse.

As is known from the laboratory tests, under continuous (or almost continuous) illumination, most farm crops complete their growth in 2-3 months, i.e. in space greenhouses, we could get 5 - 6 crops per year. It is evident that even now we should start on the development of productive plants that would be most effective in space.

It appears to us that the main difficulties in organizing the extra-terrestrial colonies will be the medical-biological problems. However, the successes gained in practical cosmonautics lend us certainty that these difficulties are surmountable.

The transformation of nature on the scale of the solar system will occur under the most advanced social structure, namely under Communism. The colossal reserves of energy, raw material and space; the possibilities of the use of vacuum and a wide range of temperatures; the conditions, optimal for man and plants, of an artificial dwelling environment; the advantages of weightlessness--all these aspects will permit a rapid increase in mankind's rate of progress.

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ENERGY SCALE OF THE PROBLEM OF CHANGING THE ORBITS OF PLANETS /127

I. A. Merkulov

Truly, there is no limit to the power of human intelligence. People are successfully solving, one after another, more and more grandiose scientific problems.

In 1911, Tsiolkovskiy wrote: "Mankind will not stay eternally on Earth, but in the quest for light and space, he will initially penetrate timidly beyond the limits of the atmosphere and will then conquer circumsolar space".[1]

At the present time, many of the ideas of the famous scientist have already been converted to reality. The Soviet cosmonauts have opened for mankind the road into the expanses of the Universe. The days of the accomplishment of interplanetary flights are approaching.

Each great accomplishment has involved the formulation of new, still more grandiose problems.

The successful accomplishment of flight to the other planets naturally raises the question before mankind, whether for a more complete and broader utilization of the entire diversity of the resources of the solar system, we should not realize the shifting of certain planets into other orbits, draw them nearer to the orbit of the Earth, i.e. accomplish a reconstruction of our planetary systems.

With the present arrangement of planets, some of them are almost entirely unsuited for human life. For instance, owing to its proximity to the Sun, Mercury is exposed to the incinerating effect of its rays. Uranus, Nepture and Pluto move in the almost total darkness of outer space, and their surfaces, receiving too little solar energy, are lifeless deserts, imprisoned by icy /128
cold. If it were possible to move Mercury farther from the Sun, and at the same time bring the remote planets closer to it, mankind could utilize these planets many times more effectively.

It would also be of great interest to move Venus and Mars closer to the orbit of Earth. Then the heat regime of life on these planets would be closer to the terrestrial conditions.

The problem of varying the orbits of planets is extremely complex and many-faceted. To form a conclusion concerning the possibility of a solution, we must examine it in all aspects. We should clarify the question of the stability of the motion of planets in the new orbit, the perturbations in the motion of planets caused by their mutual effect at reduced distances, and the

[1]From a letter by Tsiolkovskiy to B. M. Vorob'yev dated 12 August 1911.

conditions of biological life on the planets at any given distance from the Sun.

However, it is indisputable that the first and decisive question is the possibility of shifting the planets from one orbit to another, namely, the question of the energy levels required to alter the planets' orbits. It is quite clear that if it is impossible (from the energy standpoint) to shift the masses of the planets into new orbits, all the studies about the motions of planets in these unattainable orbits will prove useless.

In the present report, we shall try to estimate the scale of the power resourses required for altering the orbits of the nearest planets: Mercury, Venus and Mars.

In order to shift a planet from one orbit to another, it is necessary to apply some external force to it. Such forces can be quite diverse in their nature. For instance, we might use the pressure of solar rays, magnified by changing the albedo of a planet, or some other forces, including those which may be discovered in the future.

Let us consider initially the displacement of planets with the aid of rocket engines.

In the use of a rocket engine, imparting acceleration to a planet or to another large attracting mass, in the calculation of the thrust, it is necessary to take into account the circumstance that after the efflux from the nozzle, the gases will be subjected to the attraction of the planet, and if the exhaust velocity is less than the escape velocity for the given planet, the gases escaping from the nozzle (even when no atmospheric resistance exists) will not go beyond the limits of this attraction and hence will not develop thrust.

If the velocity of the gases or other material particles escaping from the rocket engine is higher than the second space velocity (parabolic), in the absence of an atmosphere or with installation of the engine beyond its limits (for example, on mountains), the flow of the mass having escaped from the engine will overcome the attraction of the planet, but will be separated from it at a velocity less than the exhaust velocity. The value for the velocity of separation of the gases from a planet will approximately equal: /129

$$U = \sqrt{W^2 - W_a^2}$$

where W = the velocity of the mass flow at the outlet of the rocket engine, W_a = the parabolic velocity, U = the velocity of mass flow beyond the limits of the sphere of the planet's attraction.

The value of the thrust force with which the rocket engine acts upon the planet under these conditions equals

$$P = mW\sqrt{1 - \left(\frac{W_a}{W}\right)^2} + Sp_c$$

where M = the consumption of mass per second, S = the area of the nozzle's output section, P_c = the static pressure of gas in the output section of the nozzle (in this connection, the atmospheric pressure is assumed equal to zero).

The Tsiolkovskiy formula for the motion of a planet or of another large attracting mass under the effect of a rocket engine will acquire the form (at constant consumption of mass per second):

$$\frac{M_0}{M} = e^{\frac{V}{W\sqrt{1-(W_a/W)^2} + Sp_c/m}},$$

where V = the increment in the planet's velocity, M_0 = the mass of the planet prior to activation of engine, and M = the mass of the planet at the end of engine operation.

In the calculation of the value for the velocity increment required for altering the orbit of a planet, one should select the trajectory of the transition of the planet from one orbit to another, similar to the way this is done in calculating the change in the orbit of Earth satellites.

The most advantageous trajectory from the viewpoint of consumption of mass is the transition along a Hohmann ellipse or, as it is often called, a two-pulse system. For the achievement of such a transition, as is known, we require engines with high thrust, i.e. capable of imparting to the body on which they are installed a considerable acceleration. If low-thrust engines, imparting slight accelerations to a space vehicle (less by several orders /130 than the acceleration of gravitational force) are used, the transfer from orbit to orbit is achieved along spiral trajectories with a gradual separation from the initial orbit, and an approach to the intended orbit. Such a transition requires a greater increment in the characteristic velocity and naturally a greater consumption of mass than the transfer according to a two-pulse system.

Since we are not considering here questions of the sizes of the engines, as an initial example, we can study the problem concerning the alteration in the orbits of planets under the assumption of a transfer according to a Hohmann ellipse.

The transfer of a planet from one orbit to another was computed in the following way:

The value of the velocity which the planet should receive in order to transfer from its own orbit to an elliptical orbit with high eccentricity was calculated according to the equation

$$V_1 = V_0\sqrt{\frac{2R_H}{R_0+R_H}}$$

where V_0 = the velocity of the planet during its motion in its own orbit, R_0 = = the radius of the planet's orbit, and R_H = the radius of the new orbit.

The value of the planet's velocity at the point of contact of the transitional elliptical orbit and the new circular orbit is

$$V_2 = V_1\frac{R_0}{R_H}.$$

The value of the velocity which should be possessed by a planet in order to move to a new circular orbit is

$$V_H = V_0\sqrt{\frac{R_0}{R_H}}.$$

The value of the total change in velocity is

$$\Delta V_\Sigma = \Delta V_1 + \Delta V_2 \quad ,$$

where

$$\Delta V_1 = V_0\left[\sqrt{\frac{2R_H}{R_0+R_H}} - 1\right]$$

and

$$\Delta V_2 = V_0 \sqrt{\frac{R_0}{R_H}} \left[1 - \sqrt{\frac{2R_0}{R_0 + R_H}} \right].$$

The transfer of a planet from one orbit to another can be represented as follows: Let us assume that we wish to transfer the planet Mercury from its orbit 57.85 million kilometers from the Sun into a new orbit, lying between the orbits of Venus and Earth, for example, to a distance of 120 million kilometers from the Sun. For this, initially we should impart to Mercury a velocity increment of 7.73 km/sec in such a way that its velocity would increase from 47.84 km/sec. to 55.57 km/sec. Having such a velocity, Mercury will begin to move through an extended ellipse, and at the aphelium will be separated from the Sun by 120 million kilometers. However, having separated by this distance from the Sun, it will move with a total velocity of 26.79 km/sec. For motion through a circular orbit with a radius of 120 million km, a velocity of 33.21 km/sec is required. Hence, it is necessary to impart to Mercury a second velocity increment of 6.42 km/sec. The total velocity increment will comprise 14.15 km/sec. /131

To shift Mercury from its orbit into an orbit close to the Earth orbit, it is necessary to impart to it a total change in velocity equalling about 17 km/sec.

To bring the Venusian orbit ($R_{♀}$ = 108.1 million km) closer to the Earth's orbit, it is necessary that the total increment in velocity comprise slightly more than 5 km/sec. For a transfer to an orbit close to the Earth orbit, Mars should initially receive a change in velocity (braking) in its orbit R_0 = = 227.73 million km), of 2.68 km/sec, and then at the perihelion of the transient ellipse it should receive a second retardation of 3.35 km/sec. In this connection, the total change in velocity would comprise 6.03 km/sec.

It appears quite impossible to impart to the planet the indicated change in velocity with the aid of rocket engine utilizing the energy of chemical reactions. An elementary calculation based on Tsiolkovskiy's formula shows that in order to impart to a rocket an increment in velocity of 17 km/sec, a tremendous supply of fuel is required. For example, at a gas velocity of 3 km/sec, the required supply of fuel surpasses by almost 300 times the weight of the rocket itself. Which means that even if we succeeded in building chemical rocket engines, the gases of which, having escaped beyond the limits of attraction of Mercury, would separate from this planet at a velocity of 3 km/sec, even in this case we would succeed in shifting into Earth orbit only 1/300 of the mass of Mercury, while the entire remaining mass would have to be converted to fuel and consumed for the displacement of the planet.

However, another pattern is formed if we use electric rocket engines. /133
In Fig. 1, we have shown the dependence of the required consumption of mass on the velocity of the flow escaping from an electro-rocket engine, for transferring Venus and Mars into different orbits. For example, there is a possibility

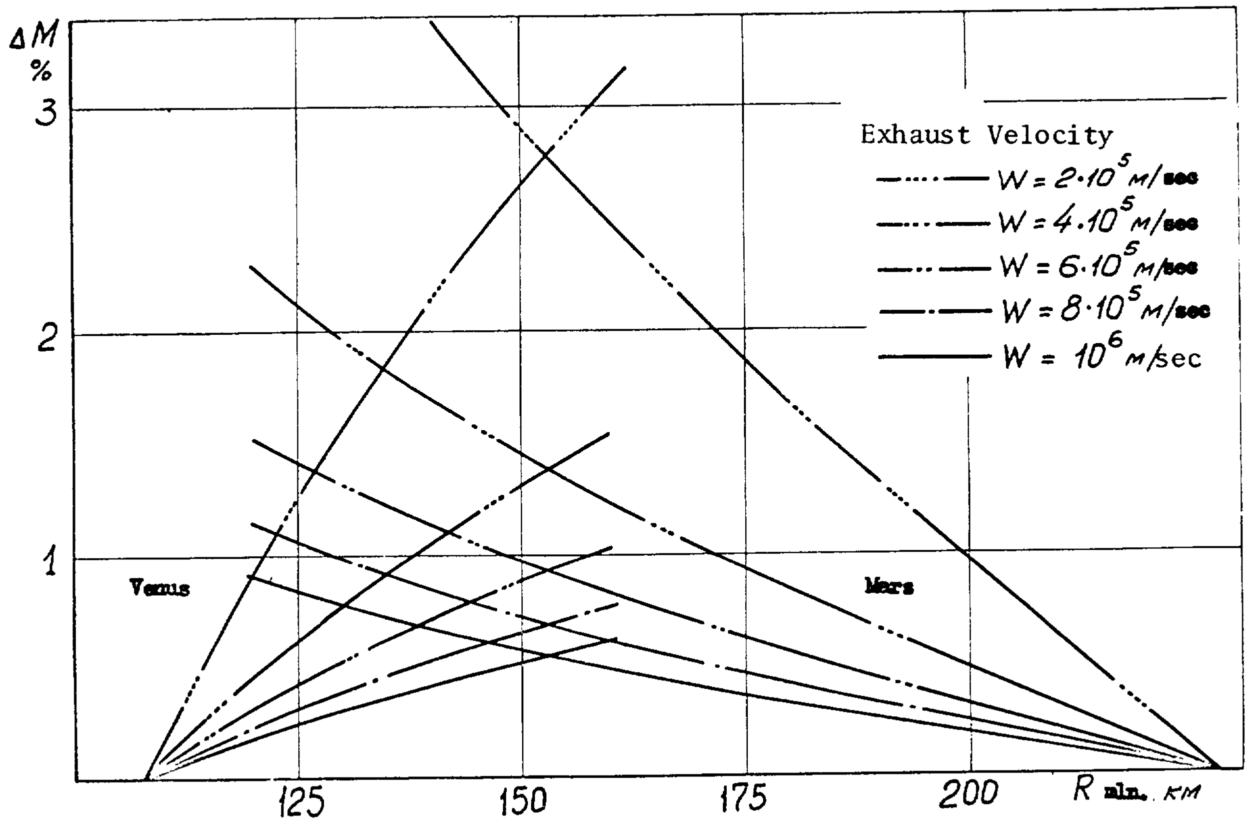

Fig. 1.

that these engines can eject a flow of matter at a velocity of 400 km/sec; in order to reduce the average distance between the orbits of Mars and Earth from 78 to 30 million km, it will be necessary to expend around 1% of the Martian mass. The mass of this planet is about ten times less than the mass of Earth. Its value in kilograms is expressed by a number with 23 zeros $6.35 \cdot 10^{23}$ kg). One percent of this vast quantity of substance would have to be converted to plasma or to a flux of ions, and be accelerated in electromagnetic or electrostatic fields.

As we shall observe, in the use of electro-rocket engines, the problem of altering the orbit of a planet, although it is not absolutely unaccomplishable, in practice for future ages, will be exceedingly difficult.

For the accomplishment of such tasks, we require other sources of energy and other types of rocket engines. For example, if we utilize a thermonuclear reactor, i.e. the reaction of the synthesis of helium of hydrogen, or some other reaction with the same release of energy, directing the entire energy derived to the acceleration of the reaction products, we can obtain a velocity of several tens of thousands of km per second. The consumption of material required for altering the orbit of planets will be reduced by hundreds of times. A still greater effort can be obtained by the annihilation of matter, when it is converted to a flow of photons, moving at a speed of 300,000 km/sec. If we could achieve this process on Mars, by consuming a quantity of matter equalling 0.001% of the entire planetary mass, we can shift Mars into an orbit lying at a distance of 30 million km from the Earth orbit. If we increase the consumption to 0.002%, we can displace Mars into an Earth orbit (of course, having placed it at a great distance ahead of or behind Earth in the direction of flight, in order that the planet would not collide and would not disrupt its uniform motion).

In the utilization of the annihilation of matter, the separation of Mercury by 140 million km from the Sun (so that the distance between the orbits of Mercury and Earth would comprise about 10 million km), would require the consumption of matter equalling 0.005% of the mass of Mercury (which comprises $3.27 \cdot 10^{23}$ kg).

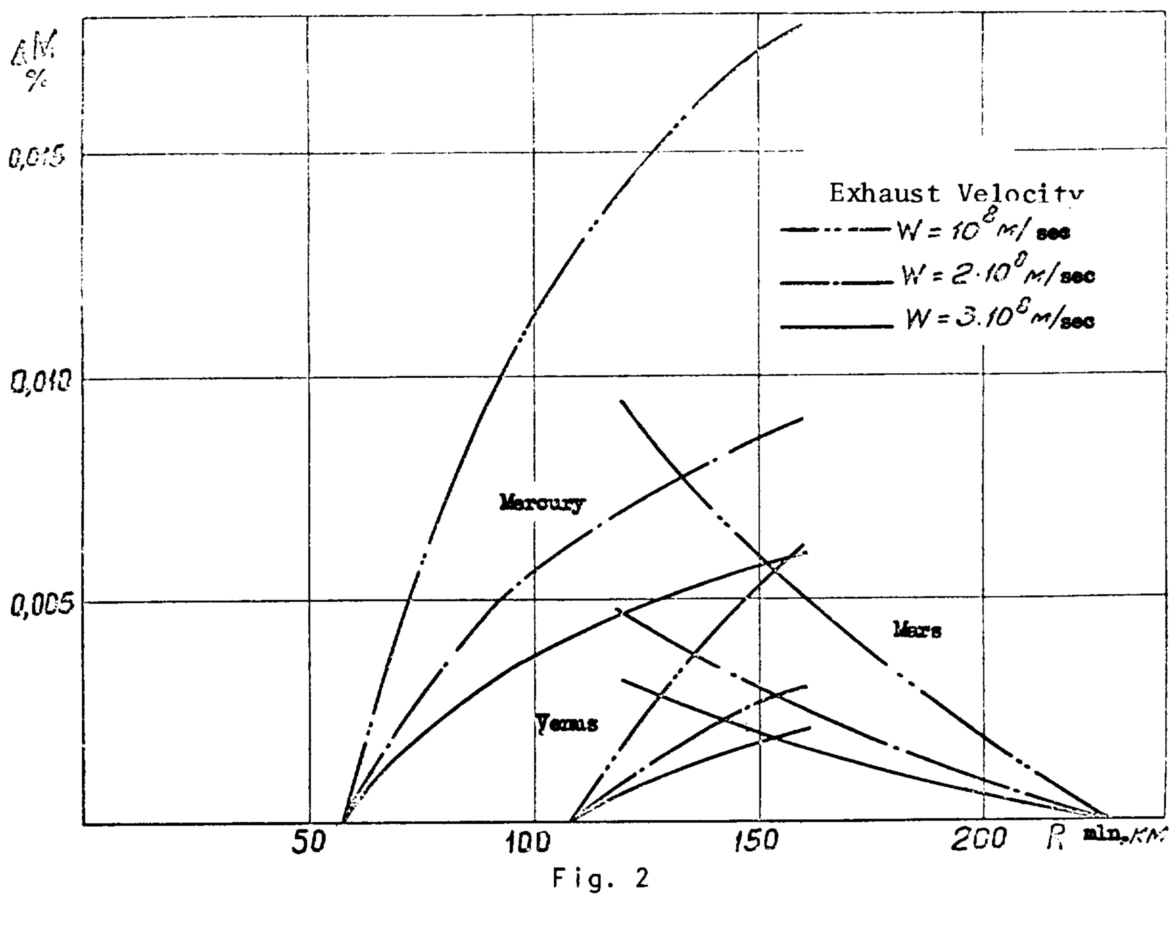

Fig. 2

In Fig. 2, we have shown the value of mass , required for altering the orbits of planets at an escape velocity on the order of the speed of light. /135

Of course, it is necessary to keep in mind that the transfer of planets into new orbits considered here according to a two-pulse system is only a provisional marginal case. It is quite clear that it does not appear possible to annihilate the amount of matter indicated in the graphs in the course of two short pulses. The alteration of the orbits of planets can be conceived only in the course of an incomparably longer time, and transpiring through some given spiral projectories.

In conclusion, we should stress once more that the problem of altering the orbits of planets is not exhausted by questions of power. In an evaluation of the possibility of the reconstruction of the solar system, astronomers should express their important ideas, and above all specialists on celestial mechanics. However, what is important and decisive here is power engineering, and the assessment of the energy scale of the problem of altering the orbits of planets shows that this problem for all its apparent improbability, does not go beyond the scope of the possible. Relying on the force of his mind, man cannot only conquer but also reconstruct the cosmos.

Of course, such problems pertain to the very remote future. Probably more than a century will pass before people will be able to change the orbits of planets, but the calculations accomplished indicate convincingly that even such grandiose problems are within the power of man and that there is no limit to the might of human intellect.

HOW K. E. TSIOLKOVSKIY WORKED ON THE PROBLEM OF DEVELOPING A DIRIGIBLE /136

Ya. A. Rapoport

For his entire conscious life, Tsiolkovskiy was engaged with the problem of the dirigible as a means for air transport.

While he was still a youth, having arrived in Moscow to round out his education, he learned from a physics textbook of the lifting force of heated air and the first aerostats. Even then, he developed the concept of the construction of an aerostat in the form of an elongated ship filled with hydrogen.

On 17 September 1966, exactly 80 years had passed from the day Tsiolkovskiy had written "Theory and Test of an Aerostat Elongated in the Horizontal Direction"; he began the preparation of this report in the Summer of 1885 and finished it on 5 September 1886 according to the Julian calendar (on the 17th according to the Gregorian calendar). This report formed the basis for his works in the field of dirigibles.

In this paper, Tsiolkovskiy considers the problem from various aspects. At the beginning of the study, he expounds the basic precepts of air navigational aerology and aerostatics. Specifically, the author devotes attention to the importance of the temperature effect of the gas and air on the buoyancy of an aerostat. Usually, not enough attention had been paid to this question; this caused a number of catastrophes. Then the various questions were examined pertaining to the frame of an elongated aerostat: formulas were derived for the estimation of the surface dimensions, the cross-sectional areas, etc.; an experimental and analytical investigation was discussed regarding the forms of the cross-section and the tension of the aerostat's shell. In this same place, Tsiolkovskiy suggested a filament model of the cross-sectional form of a cylindrical aerostat, permitting a simultaneous reproduction both of the surplus gas pressure and of the shell weight. With its aid, studies were made of the cross-sectional form with suspension of the load to /137
the lower meridian, to the upper meridian of the shell, and with varying length to the internal suspension. After many years, similar studies were repeated in England and Italy, independently of Tsiolkovskiy. Having arrived in the Soviet Union in 1930, the Italian designer Nobile brought along a similar filament-type model. However, in it (as in the English models), the shell weight had not yet been reproduced.

In this report, Tsiolkovskiy also discussed in detail the theory of longitudinal stability of an aerostat and investigated the means of its attainment (the method of vertical bracing of the shell and the natural contraction of the shells by the weight of the ship).

Taking cognizance of the times, Tsiolkovskiy at the outset of the cited report still did not regard the shell as the supporting design of the airship.

He relegated a considerable amount of attention in his report to the development and study of the design and strength of wire mesh.

Comparing the potentialities of electrical, "caloric", gas-type and steam-driven engines, Tsiolkovskiy gave preference to the latter, although he indicates the possibility of transferring later to internal combustion engines. Further, he expounds the elements of the propeller screw theory, whereupon he discussed the vertical control of the ship. He examines the questions of compensating the consumption of solid or liquid fuel by the cooling of a preheated gas, and also the compensation of gas consumption by its heating.

The idea suggested by Tsiolkovskiy of fastening weight to the upper part of the shell by means of an internal suspension (see "Theory of an Aerostat") was lost for over 50 years, and toward the outbreak of the Second World War, all the dirigibles came to be equipped with internal suspension.

In the Spring of 1887, at a meeting of the Society of Naturalists in Moscow in the Polytechnical Museum, Tsiolkovskiy lectured on his concepts of a metallic controlled aerostat. The lecture was received favorably. Tsiolkovskiy assumed naively that as soon as the theory became known about the metallic controlled aerostat and the advantage predicted by this theory became publicized, people would be found who would plan, build and begin to utilize the dirigible. To his embarrassment, nothing of the kind transpired. He understood that it was necessary to continue the work in justifying subsequent plans.

In 1890, Tsiolkovskiy completed a new paper: "On the Possibility of Constructing a Metallic Aerostat", and through D. I. Mendeleyev, he sent it to the Imperial Russian Engineering Society. Along with the paper, he sent a /138 model of the aerostat, formed in plane. The basic theme of the paper was a discussion of the theory of an elongated metal shell able to alter its cross-sectional shape and to change its volume. In this paper, he had already abandoned the idea of a mesh thrown over the shell. The shell was regarded as the ship's hull.

This comprised one of the original studies in the general theory of shells.

It is of interest to present the conclusion of the Administrative Section of the Imperial Russian Engineering Society, which did not debate the validity of Tsiolkovskiy's theoretical calculations, but expressed itself in the words of its chairman, Fedorov: "The aerostat is forever doomed by the nature of things to remain a plaything of the winds".

Having received such a conclusion, Tsiolkovskiy continued his work with renewed vigor, devoting much time and effort to theoretical and experimental aerodynamic studies. He built a wind tunnel (a handmade fan, which was activated by the force of a falling weight), prepared with his own hands many aerodynamic models of an aerostat shell, and also made wings of verying profiles, including thick ones. He developed much important data concerning the drag of these bodies and the lift of a wing; he discovered the law concerning the friction of air.

The research findings were expounded in a new report by the scientist "A Metallic Controlled Aerostat" (first edition, 1892; second edition 1893). Specifically, in this report, he gave a more detailed and precise calculation of the cross-sectional form of a shell and also described a new (hydrostatic) method of studying the form of a shell with the aid of air-filled flexible models submerged in a tank.

In the following period of his work on the dirigible, Tsiolkovskiy, carrying on his aerodynamic investigations, began to build many models of shells, first of paper and then of tin. One event predetermined the further trend in the development of his planned dirigible. Konstantin Eduardovich Tsiolkovskiy was to substitute for a geography teacher who had fallen ill. There was no world globe in the school and Tsiolkovskiy made one at home of papier-mache. After cutting in half the paper model of the globe, which had covered the round wooden form which he had carved out in advance, he noticed that the halves curled up and acquired a spindle-like form. The law of the flexibility of convex surfaces and the displaceability of rotation surfaces /139
thus discovered by him, convinced him of the fact that the contraction (collapsing) of the metal shell of a dirigible would not be accompanied by extensive deformations and that no insurmountable requirements would be imposed for extending its corrugated walls. This determined the final selection of the internal suspension of the power system, its fastening to the shell and the contraction of the shell, as a means of control by surplus gas pressure without air tanks.

Konstantin Eduardovich was also concerned with the question of stabilizers for dirigibles. He drew attention to the fact that in the empennage of birds, fish and sea animals, there are no stabilizers and in this sense he stated that a "dead" stabilizer is less suited for supporting the stability of an airship in flight than quick reaction of the rudders. The boats which he built did not have keels, were very nimble, but the skill required to control them was quickly acquired. The boats did not list and, in the words of Tsiolkovskiy, in their day were the fastest on the Oka River (the story about the World globe and the boats was related to me by Tsiolkovskiy himself).

In 1905 - 1908, the journal *Vozdukhoplavaniye* printed the report by Tsiolkovskiy "Aerostat and Airplane", which constituted a continuation and more detailed exposition of the unpublished paper "Theory and Experiment of an Aerostat". The calculations for the deformation of a shell and the designs of the corrugation were given in this monograph in an expanded and generalized form. Along with a series of supplements, data and estimations were presented, discussed earlier in the report: "A Metallic Controlled Aerostat", concerning the deformation of a shell, etc. The publication of the work was not completed. The last chapters: "Motion of an Aerostat" and "Heating of Lighting Gas" were published only in the third volume of the scientists Collected Works, published in 1959.

Tsiolkovskiy was not an introverted scientist; he was also an energetic popularizer of his ideas. In his published articles, he aimed at the lay reader, attempting to avoid thereby as much as possible the use of complex mathematical formulas. In this spirit, he wrote: "Simple Lesson on an Airship and Its Construction". Here he gave a popular explanation of the fundamentals of aerostatics and a description of a dirigible made of corrugated metals with a capacity of around 75,000 cubic meters, with internal suspension and natural contraction of the shell (the first edition appeared in 1898; the second in 1904).

Taking into account the difficulty of the construction of the corrugated shell of a dirigible, Tsiolkovskiy suggested that an intermediate design of /140 the shell be made of smooth sheets, tightly interconnected by cloth strips. Persons who held an identical opinion with Tsiolkovskiy advised him to take out a patent on the invention of the dirigible. However, it turned out that the preliminary publication of the works about the dirigible made of corrugated metal deprived the inventor of the author's rights; therefore in a number of countries, patents were obtained only for a dirigible made of smooth sheets.

The idea of a tight connection of the sealed walls with soft bands proved fruitful. At the beginning of the 1950s, in America and Western Europe methods were introduced for the construction of watertight structures (reservoirs, dams) made of blocks (units) connected either flexibly or rigidly by soft bands of the same configuration which was described in Tsiolkovskiy's 1911 patents.

In addition to the tin models of shells, capable of changing their volume, Tsiolkovskiy also made and tested some paper models. Of particular interest were the shells with sides made of corrugated paper, both equipped and not equipped with straight cross-strips of heavier paper.

The observance of their "inflation" gave Tsiolkovskiy the incentive to replace the arc-shaped waves in the metal shell by straight ones which corresponded to the mathematical model previously adopted by him in the calculation. This modification greatly simplified the method of assembling the sides of the dirigible's shell from long, longitudinally-corrugated straight strips. The very first test of the construction of such a corrugated shell made of sheet tin proved quite successful. It was described in the illustrated brochure "First Model of a Purely Metallic Balloon Made of Corrugated Iron" published by the author in Kaluga in 1913.

Concurrently with his research activity, Tsiolkovskiy continued to be busily engaged with promoting his dirigible and air navigational transport. The brochure "Simplest Plan of a Metal Aerostat" published in 1914 described in laymen's terms the design of a dirigible and its properties, as well as a method for the vertical assembly of the dirigible with straight corrugations on the sides. In 1915, in the brochure "Additional Technical Data on the Construction of the Metal Hull of a Dirigible Without an Expensive Docking Facility", he briefly described the results of investigation, with the aid of hydrostatic models, of the process of gas filling (on a flat platform) of a metal shell assembled on it in a plane form. These drawings were also repeated in the brochure: "Gondola of Metal Dirigible and Elements for Its Control". Here, a diagram is also given of a horizontal docking facility for construction of the shell. In order to augment the rigid longitudinal strips (of the shells' bases), they were fitted with triangular tubes made of corrugated material. /141

Subsequently, K. E. Tsiolkovskiy invariably adhered only to horizontal assembly of the dirigible's shell. The successive experiments conducted by him in models made of cold-worked brass had the purpose of developing a fully elastic shell and were completed successfully in early 1925.

My first acquaintance with Tsiolkovskiy occurred in December 1924 at the time of his completion of work on a brass shell four meters in length. I recall that for 10 1/2 hours, with a brief stop for lunch, he expounded to me his ideas on a dirigible and made me his assistant in the course of, as he wrote to me later, "an 11 years' friendship that was never darkened".

From this time, Tsiolkovskiy confined himself strictly to office work; however, his experiments were conducted in Moscow in accordance with his plans and instructions.

In 1926, according to the drawings and the engineering diagram developed by him, an elastic brass shell two meters high and 10 meters long was prepared and assembled for the first time. The photographs of this shell are in the holdings of the House of Aviation and Cosmonautics. At this very same time, Tsiolkovskiy's plan of experimental activities was augmented by the priority problem of finding an industrial technique for the permanent, tight connection of steel sheets. Resistance roller electric welding was proposed for its solution. In 1927, with the cooperation of an electrical plant, we succeeded in obtaining durable specimens of welded joints of cold-worked steel with a thickness of 0.15 mm. The continuation of the tests was conducted in the Prof. N. Ye. Zhukovskiy Academy in 1928.

In 1930, Tsiolkovskiy published the paper: "Plan of a Metal Dirigible for Forty Persons", in which he described a simplified plan of a dirigible with a shell 20 m high and 120 m long. Its over-all capacity was 23,600 cubic meters. The design was welded, made of stainless steel, with sides 0.15 mm thick and longitudinal strips 0.45 mm thick, including a sealing system and a device for heating the gas. A detailed static calculation of the dirigible is presented in the report.

We see a number of innovations in this plan: a very real development of the design of sealing system and its control; the arrangement of the rudders in the jet emitted by the impellers, and a design of flexible rudders. We note that in the most recent times, information has been received about American tests in the construction of aircraft with wings which bend in such a way that their trailing edges can be lowered and raised. This is a very effective means for controlling the lift of an airfoil. In addition to the descriptive and calculated parts, the plan contains a chapter "Sequence of Practical Tasks in the Construction of a Metal Dirigible", in which a program is shown for phased tasks, assuring the creation of the dirigible. As the fifth point in this program, the author wrote: "Machines--The Tools for the Rapid, Precise, Improved and Economical Production of Parts to Full Scale". /142

These included welding, corrugating, stamping and rolling machines of various sizes, purposes and arrangements.

In 1932, Tsiolkovskiy sent me an information copy of this "Plan" including corrections; the gist of them reduced to the following: the shell thickness and all the linear dimensions were reduced by 20%, while the volume was roughly doubled. The thickness of the sides was 0.12 mm, and the capacity was 12,000 cubic meters. He proved to be more daring than us, his students in the Tsiolkovskiy Design Bureau for Dirigible Construction, who worked later on a dirigible design with a capacity of 8,000 cubic meters made of steel 0.15 mm thick.

At the end of 1930, the All-Union Combine of the Civil Air Fleet, called Aeroflot, was created in which work was renewed on developing Tsiolkovskiy's dirigibles. In the Summer of 1931, a small group of Aeroflot workers, having formed the Bureau of Experimental Dirigible Construction, succeeded in building the first welded shell made of steel 0.1 mm thick; in plane suspended form, it had a height of 1 m and a length of 7 meters, including, to be sure, digressions from the technological plan developed by Tsiolkovskiy for building the shell. In the same place, a new welding machine was developed and tested for assembling metal panels of unlimited size, complying with Tsiolkovskiy's specifications. Later on, in Dirigible Construction (on the basis of this system) mobile roller-type welding machines were planned, built and tested. In 1933, one of them was utilized for the construction, with precise observance of Tsiolkovskiy's engineering plan, of an all-metal shell made of stainless steel 0.15 and 0.45 mm thick. In the same place in the Tsiolkovskiy Design Bureau under the Dirigible Construction authority, a series of machines was developed for pressure treatment of a steel band, in accordance with the /143
fifth point of the "program". Simultaneously with the development of the rough plans of the dirigibles with a capacity of 3,000 and 8,000 cubic meters, work progressed on the testing and adjustment of a small stock of special machines. They were utilized for the preparation of the first model of a dirigible shell to go aloft; it had been assembled by 15 September 1935 on a horizontal platform. The dimensions of this shell during the assembly were 11 m by 44 m, with a height of 0.36 m. During filling, the shell acquired the form of a spindle 7 m in diameter. Filled with hydrogen, it raised 200 kg of ballast. The shell was assembled from stainless steel, with sides 0.1 mm thick. Even after Tsiolkovskiy's death, it was subjected to static tests

conducted in accordance with a broad program.

Up to his very last days, Tsiolkovskiy continued his enthusiastic promotion of dirigibles and of air navigation in general. Starting in 1910, he wrote around 40 brochures and journal articles on this topic. It is impossible to discuss all of the new ideas contained in them in a short survey.

Konstantin Eduardovich died while thinking of dirigibles. The final words of his famous telegram (sent just before his death) to the Central Committee of the Communist Party were: "I am convinced, I know that the Soviet dirigibles will be the best in the world".

Our common duty is to implement this concept of Tsiolkovskiy to the advantage of our country and the workers of the entire World, in a manner similar to that in which we are bringing to reality his ideas on the conquest of space.

In addition, the following lectures were presented in the Readings:

Zhdanov, G. B.: "Cosmic Rays and Explosive Phenomena in the Universe."
Ivanov, N. V.: "On the History of the First Soviet Organization for Development of Liquid-Fuel Rocket Engines."
Strong, R. P.: "The Dirigible--the Fledgling of K. E. Tsiolkovskiy."

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